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BLAST TESTS OF EXPEDIENT SHELTERS IN THE DICE THROW EVENT

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CONTENTS

Page

Page

LIST OF FIGURES

Figure		Page

LIST OF TABLES

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BLAST TESTS OF EXPEDIENT SHELTERS IN THE DICE THROW EVENT

ABSTRACT

To determine the worst blast environments that eight types of expedient shelters can withstand, we subjected a total of 18 shelters to the 1-kiloton blast effects of Defense Nuclear Agency's DICE THROW main event. These expedient shelters included two Russian and two Chinese types. The best shelter tested was a Small-Pole Shelter that had a box-like room of Russian design with ORNL-designed expedient blast entries and blast doors added. It was undamaged at the 53-psi peak overpressure range; the pressure rise inside was only 1.5 psi. An unmodified Russian Pole-Covered Trench Shelter was badly damaged at 6.8 psi. A Chinese "Man" Shelter, which skillfully uses very small poles to attain protective earth arching, survived 20 psi, undamaged. Two types of expedient shelters built of materials found in and around most American homes gave good protection at overpressures up to about 6 psi. Rug-Covered Trench Shelters were proved unsatisfactory. Water storage pits lined with ordinary plastic trash bags were proven practical at up to 53 psi, as were triangular expedient blast doors made of poles. At 53 psi, expedient blast valves installed in blast doors successfully protected the expedient air pump and allowed it to continue to force sufficient air through the shelter. However, after the blast the reopened valves allowed so much wind-blown sand to enter the shelters that it became obvious that blast valves installed in blast doors will not give adequate protection against the entry of fallout.

1. BACKGROUND AND SCOPE

Civil defense research at Oak Ridge National Laboratory has stressed the development of protection against blast and fire effects, even in the design of expedient fallout shelters. Well-constructed expedient shelters will permit their occupants to survive at least 7 psi. In contrast, most frame buildings are badly damaged by blast and may be destroyed by fire at the 2-psi overpressure range from a large-yield weapon, at great hazard to anyone taking shelter in them. Since the area covered by 7 psi is only one-quarter that covered by 2 psi by a single weapon, the lifesaving potential of good expedient shelters, built unattached to buildings, is worth working hard to attain. Another reason is that even expedient shelters, if their walls are skillfully shored and their entrances equipped with expedient blast doors, can readily be built so as to protect occupants against all blast effects at peak overpressure ranges several times as high as 7 psi. Therefore, in 1973 ORNL participated in Defense Nuclear Agency's (DNA's) MIXED COMPANY Event. This test subjected various expedient shelter designs to the effects of an explosion of 500 tons of TNT. All of the ORNL expedient shelters survived with little or no damage at overpressures up to 29 psi.[1] As a result, it was decided that the most promising designs should be subjected to blast effects severe enough to indicate the worst blast environments that these shelters are capable of withstanding.

The main event of DNA's recent DICE THROW series afforded the required blast environment. This event was a 628-ton ANFO (ammonium nitrate-fuel oil) explosion, the largest planned detonation of a conventional explosive in history. The 1,256,000 lb of ANFO is shown in Fig. 1.1, stacked in the desert at White Sands Missile Range, New Mexico. This shot was detonated on October 6, 1976, and produced air-blast effects about equivalent to a 1-kiloton nuclear surface burst.

PHOTO 6141-76

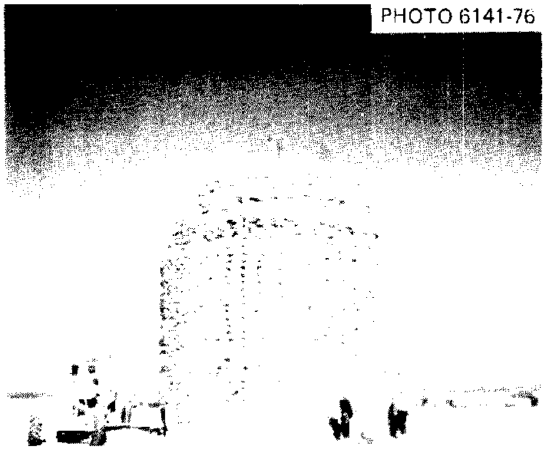

Fig. 1.1. The 628 tons of ANFO ready for detonation.

PHOTO 6391-76

Fig. 1.2. View of the rising mushroom cloud taken from an observation post 3 miles away.

Figure 1.2 is a photo taken 3 miles away from ground zero and shows the mushroom cloud while it was still rising. The winds of the negative phase were still blowing a sheet of dust and sand inward toward the rising stem of the cloud. Eighteen expedient shelters (including four half-scale models) were subjected to the blast effects at overpressures ranging from 53 to 5.8 psi, and expedient life-support equipment (mostly placed inside shelters) was exposed to overpressures of 53 to 1 psi. Several one-tenth-scale models of shelters were also tested, at overpressures of up to 180 psi.

2. PRINCIPAL OBJECTIVES

The principal objectives of ORNL's participation in DICE THROW were:

2.1. to obtain field data useful in making more reliable estimates of the practical limitations of promising expedient shelter designs and expedient life-support equipment, as regards their capabilities for withstanding all blast effects from large explosions;

2.2. to observe the relative effectiveness of several different ways of utilizing earth arching and trench-wall shoring to increase the blast protection afforded by lightly constructed shelters, in order to develop improved shelter designs that can be built using only widely available materials.

3. INSTRUMENTATION USED AND TEST DATA RECOVERED

3.1 Blast Overpressures

Blast overpressures were measured by yielding foil membrane blast gauges.[2] These passive gauges were developed at ORNL and performed well at the lower overpressures (less than 7 psi). However, the ORNL gauges that were installed adjacent to principal shelters to measure overpressures above 7 psi all recorded overpressures 28 to 60% higher than those recorded by the transducers at the same radial distances from ground zero on DNA's adjacent Gauge Line No. 1. Therefore, we have used the DNA measurements for all the aboveground overpressures to which the ORNL shelters were subjected, except for the DNA measurement at the predicted 100-psi range, which was obviously far too low.

The distances from ground zero to the shelters, the predicted overpressures, and the measured overpressures at these distances are shown in Table 3.1.

Table 3.1. Overpressures at various distances

Distance from ground zero (ft)	Predicted overpressures (psi)	Measured overpressures (psi)		
		DNA Gauge Line No. 1	ORNL gauges	Overpressure value used
440	100	66	106	106
540	50	53	68	53
640	30	31	43	31
740	20	20	32	20
820	15	15	24	15
1140	7	6.7	10.5	6.7
1370	5	5.8	6	5.8

To simplify this report, only a few references to distances from ground zero or predicted overpressures will be made. Measured peak overpressures will be used (e.g., "53 psi," "31 psi").

The ORNL pressure gauges inside the shelters recorded low overpressures. All these gauges functioned well. However, the records of two overpressures inside the shelters at the 31-psi overpressure range were subsequently lost. All the ORNL pressure gauges were recovered, and all but the two above-mentioned overpressures they recorded inside the shelters are used in this report.

3.2 Elastic and Permanent Deformations

Elastic and permanent deformations of the roofs and some other parts of the shelters were measured by passive mechanical devices.[1] Over 90% of these functioned effectively. Linear measurements of distances between parts of a shelter were taken before and after the blast.

3.3 Blast-Wind Scouring

Blast-wind scouring of the earth mounded over shelters and around entryways was determined by driving 12-in. steel spikes into the earth until their heads were flush with the ground and measuring their exposures after the blast. (The duration of the blast winds is proportional to the cube root of weapons yield;[3] thus the depth of scouring by larger weapons can be estimated.) Also, preblast and postblast depths of earth over and around shelters were recorded.

3.4 Blast Damage to Structures

Blast damage to all structural parts of shelters and to the earth walls of unshored shelters and of water storage pits were determined primarily by observation. Numerous photographs were taken, both before and after the blast, to record blast damage — the most important part of the test data.

4. SMALL-POLE SHELTER AT 53 psi

4.1 Purpose

The Small-Pole Shelter (see Figs. 4.1 and 4.2) has been developed for construction by unskilled workers in wooded areas (in stable or unstable earth, below or above ground). It provides excellent protection against radiation and much better protection against blast than does an unshored trench shelter or any poorly shored shelter. Untrained groups of families, using only muscle-powered tools, have succeeded in building this type of shelter in less than 48 hr elapsed time from the time they received the instructions.[4] A 24-man section of an infantry platoon of the 82nd Airborne Division, with no prior training and using only muscle-powered tools, built a 24-man model, without benches or bunks, in 18 elapsed hours.[5] All of these models had only one entry. The Russian-sized ventilation duct at the other end, that provided only about 10 cm^2 of cross-sectional area per occupant, was found to result in dangerously inadequate cooling during summertime tests in Tennessee.

ORNL DWG 71-3428R2

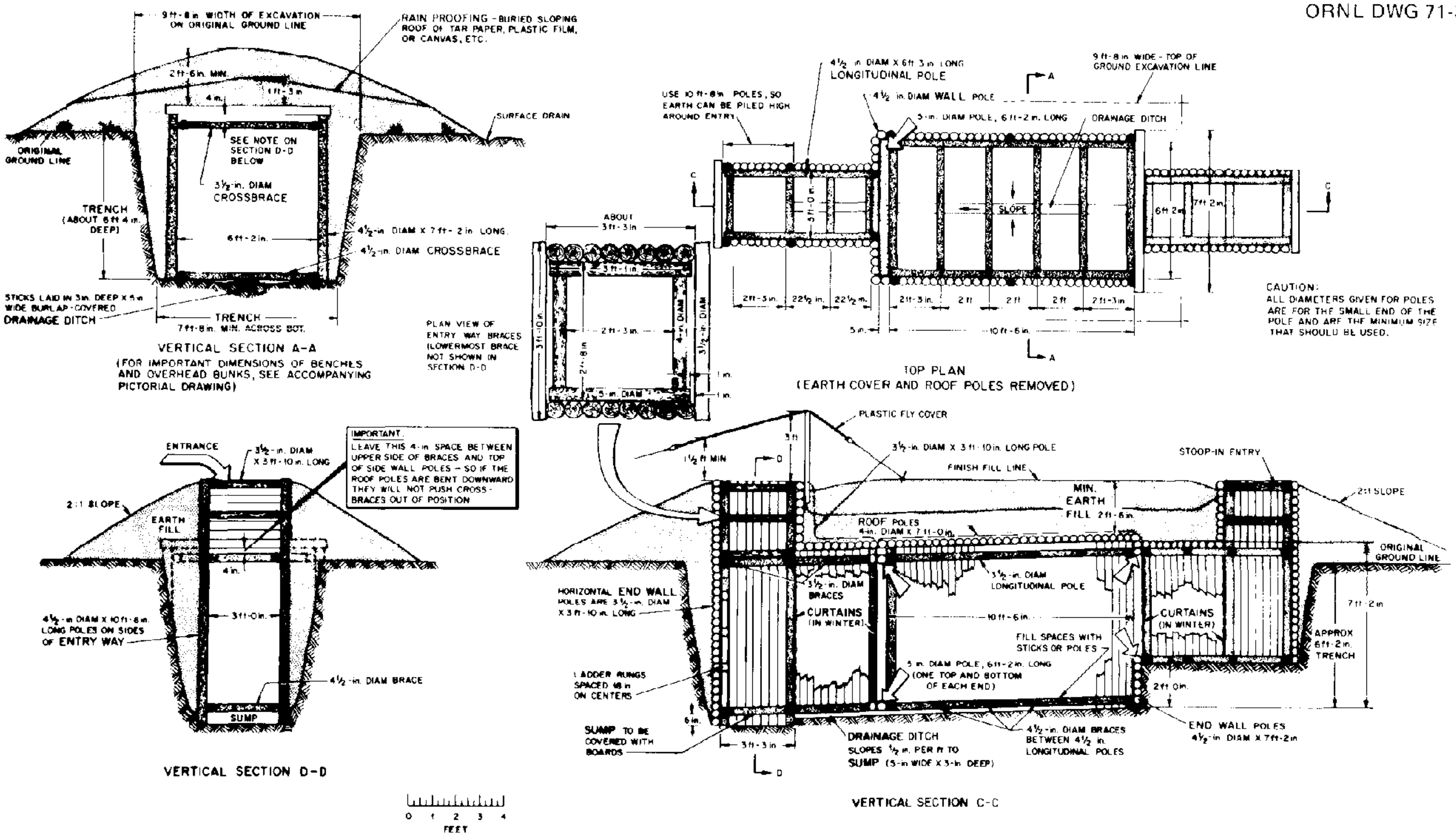

Fig. 4.1. Plan and elevation of Small-Pole Shelter.

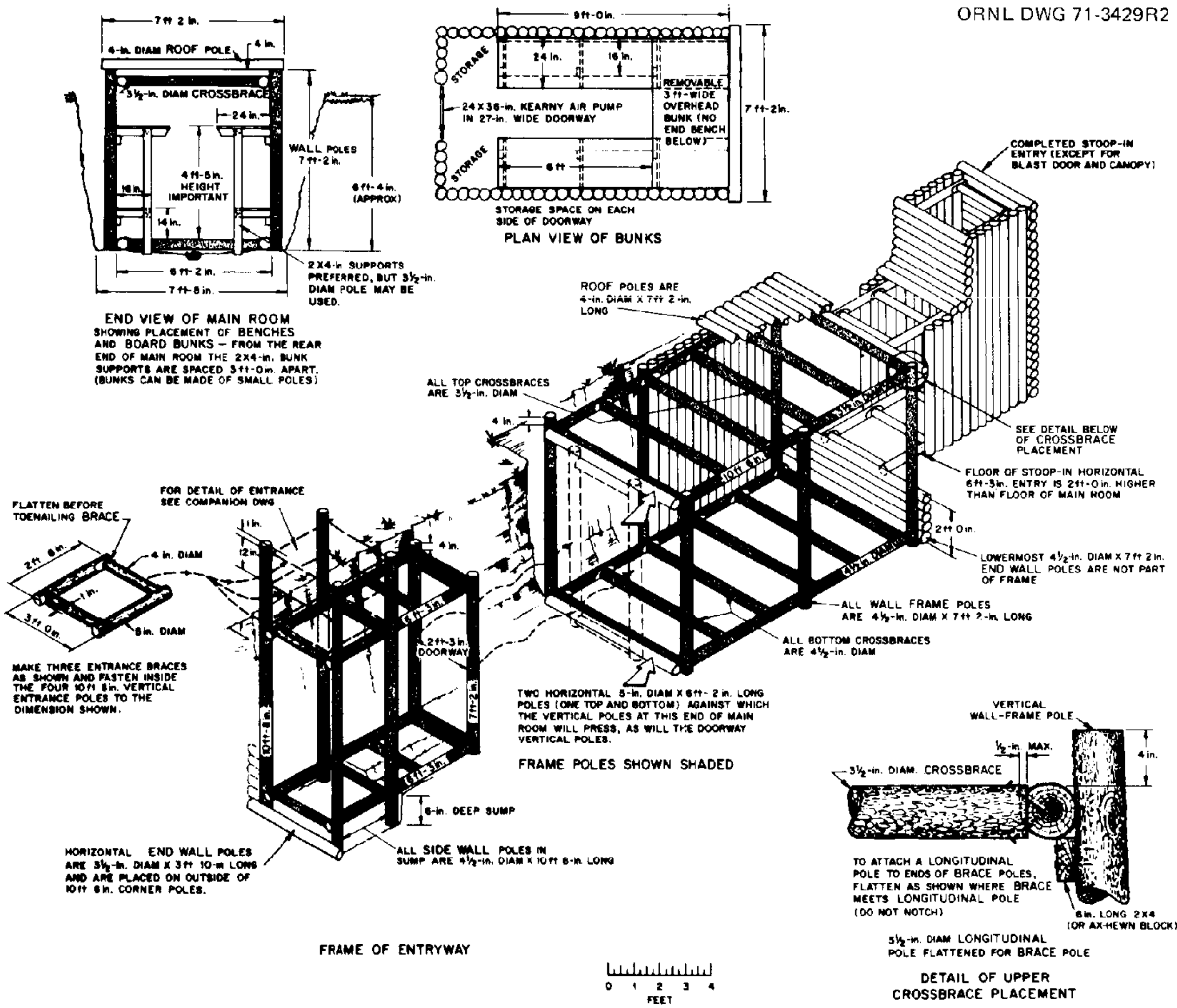

Fig. 4.2. Pictorial view of Small-Pole Shelter.

4.2 Construction

The main room and the horizontal part of the entryway at the east end were of unmodified Russian design,[6,7] except that the excavation in the hard caliche was made 2 ft deeper than the final level of the shelter floor. Then this bottom 2 ft was backfilled with dry, sandy earth. This soft earth under the wall poles permitted them to be pushed down sufficiently under blast loading to throw most of the load onto the resultant earth arching that blast overpressure sets up over a yielding structure.

A previous ORNL analysis[8] of the survivability of this shelter indicated that without the protection of earth arching it would withstand an overpressure from a 200-kiloton weapon of about 15 psi with blast doors closed. This analysis assumed the use of green hardwood poles, the strengths of which were determined in the ORNL materials laboratory. The roof poles and wall poles of all the ORNL pole shelters in DICE THROW were ponderosa pine. In this shelter the poles averaged about 5 in. in diameter, including their bark. The 12-occupant shelter room was 10-1/2 ft long, as illustrated by Figs. 4.1 and 4.2.

The horizontal part of the entryway at the south end was only 4-1/2 ft in height, with its floor 2-1/2 ft above the floor of the main room and the east-end entryway.[6,7] This height proved adequate, and this stoop-in entryway required significantly less material and labor to build than did the Russian-type horizontal entryway with 6 ft of headroom. (An unmodified Russian Small-Pole Shelter has only a small chimney-like air duct at one end; ORNL tests had proved that this small air duct would provide such inadequate ventilation that fatalities from excessive heat-humidity could result in warm or hot weather after a day of full occupancy.) The vertical entryways were of ORNL design,[7] as shown in Figs. 4.1 and 4.2, except that they extended 5 ft above the ceilings of the horizontal entryways. (The Russian inclined stairway-entrance had been found to be weak and not suitable for the installation of a blast door.)

The roof poles of this boxlike shelter were at ground level. The length of this shelter was perpendicular to the radius from ground zero. To provide adequate shielding against the initial nuclear radiation to be expected at the approximately 50-psi overpressure range from smaller nuclear weapons, the roofs of the shelter room and its entryways were covered with 5 ft of mounded earth. For adequate protection against initial radiation from a tactical weapon (through the entries), each entryway should have been at least 10 ft long. For protection against radiation from strategic weapons, the entries actually built would be satisfactory, and only 3 ft of earth cover would give a protection factor (PF) of over 500.

The need for blast doors on family shelters has long been recognized.[9,10] ORNL blast tests[1] had demonstrated the effectiveness of expedient blast doors with protector logs around them at overpressure ranges up to 29 psi, and since the present Soviet nuclear arsenal could subject over half of all Americans, if in their normal areas, to serious blast dangers, we included three new designs of expedient blast doors in our DICE THROW tests.

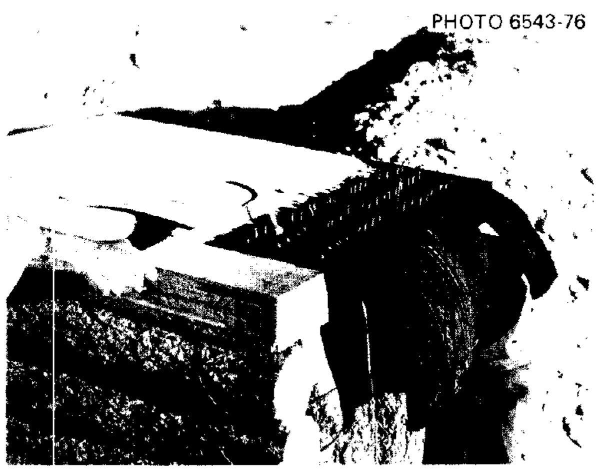

Fig. 4.3. Nailing tire-strip hinges to expedient blast door tested at the 53-psi overpressure range.

Both entrances of the Small-Pole Shelter were protected by expedient blast doors (see Figs. 4.3 and 4.4). Each door measured 48 × 42 in. and each was made of five thicknesses of 3/4-in. exterior plywood. The plywood sheets were glued together with waterproof resin and nailed together from both sides, on a rectangular spacing of 4 in. in each direction, with No. 16 (4-in.) coated nails. Expedient hinges made of strips cut from the worn treads of automobile tires were nailed to the

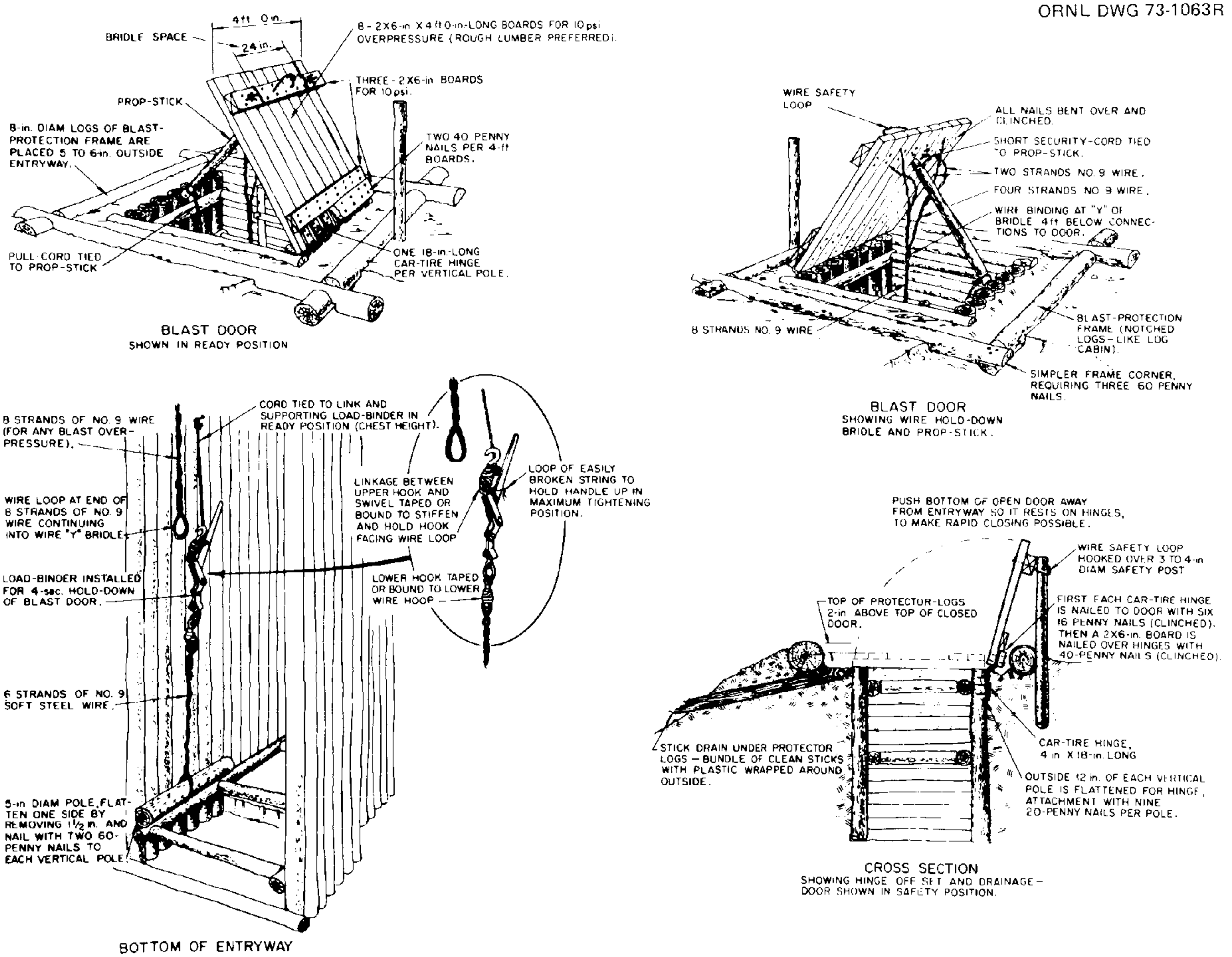

Fig. 4.4. Expedient blast door that can be closed and secured in 4 sec. The expedient blast doors tested at DICE THROW were all of stronger construction than this door made of boards. This door was damaged but still intact after being subjected to about 17 psi in the main explosion of DNA's MIXED COMPANY Event.

door and to vertical poles of the entry. A door was hinged on its side nearest ground zero with five hinges nailed with 5-in. nails to the five vertical poles of this side of its vertical entry. Each hinge was a 24-in.-long strip of worn, wide-tread automobile tire, 4 to 6-1/2 in. wide and 1/4 to 1/2 in. thick, measured in the grooves of the tread. Each strip was nailed to its door with twelve 5-in. nails, driven in about 3-1/2 in., with their heads bent away from the hinge line.

After seeing the bright light from a nuclear explosion, an alert shelter occupant can close and secure this type of door within 4 sec. This is fast enough to effect the closure of the door before the arrival of the air-blast shock wave from an 8-megaton or larger weapon at the 20-psi or less overpressure range, but not fast enough at the 53-psi range. Therefore, if this shelter is to afford protection against tactical weapons, it should be equipped with expedient blast valves of the tire-strip type (Fig. 4.5), installed in separate intake and exhaust shafts. This type of valve installed in an air shaft 2 ft above its bottom, has been blast tested without being damaged at 65 psi.[1]

ORNL DWG 73-2229

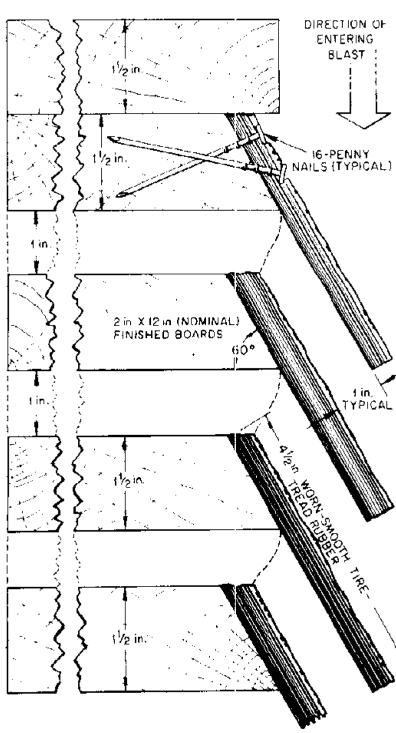

Fig. 4.5. Vertical cross section through an overlapping-flaps blast valve. The tested valve had four open-air slots, each 1 in. high and 10 in. wide. The overall width of the housing was 18 in.

PHOTO 6545-76

Fig. 4.6. Blast-protector logs around blast door after these logs were moved by blast effects at the 53-psi overpressure range.

Each blast door was surrounded with blast-protector logs which had been notched and spiked together and were evenly spaced around the door (see Fig. 4.4). These logs (about 8 in. in diameter and 8 ft long) had been placed with their upper sides about 2 in. higher than the top of the closed blast door. Without blast-protector logs, the reflected shock overpressure against a vertical side edge of this type of door could be several times as great as the free-field peak overpressure.[11] At the 53-psi overpressure range, this reflected peak overpressure, that would move the closed door horizontally, could be as much as 77,000 lb. We believe that the door hinges and hold-down attachments of an expedient door could not withstand this great a horizontal force. Furthermore, stout blast-protector logs give an aboveground blast door some protection against the heavy objects that in most areas would be hurled by a large nuclear blast.

4.3 Test Results

Figure 4.6 shows the four blast-protector logs around the north-end door after the blast. This explosion produced a measured peak overpressure of about 53-psi and a calculated peak blast-wind velocity of about 1000 mph at this range (i.e., 540 ft from ground zero). The blast winds blew away up to 12 in. of the dry earth previously piled around the blast-protector logs. The shock wave and dynamic drag effects shifted these four logs from their original positions. In its final position, the log nearest ground zero was so close to the hinges that the door could be opened from the inside to an inclination of only about 60°.

If this door and its protector logs had been subjected to the same overpressure from a large surface burst that would have produced dynamic drag and blast-wind effects of much longer duration, the door might have been jammed in its closed position by the shifted logs. If long, strong stakes had been driven prior to the blast so as to secure the logs, their movement would have been reduced. However, for maximum blast protection against nuclear weapons, this whole shelter should have been positioned deep enough in the earth so that its blast doors would have been only a few inches above ground level, with the earth surrounding the blast-protector logs sloped up around them at an angle of about 10°. (The slope angle of this mound was 36°.) Or the earth mounded over the whole shelter should have all its slopes less than 10° if the earth is dry and sandy.

PHOTO 0704-77

Fig. 4.7. Small-Pole Shelter after being tested with blast doors closed at the 53-psi overpressure range. Note the slightly damaged expedient shelter ventilating pump in the stoop-in entryway. Two men worked about 5 min to replace the four blown-loose flaps, the only damage.

The pole frame and plywood blast doors of the Small-Pole Shelter were essentially undamged by the blast effects at the 53-psi overpressure range (see Fig. 4.7). However, occupants would have been injured if they had been standing with their heads close to the ceiling, which was rapidly depressed when pressure on the roof poles caused the wall poles to be punched down into the soft, backfilled earth supporting them. This downward movement of the roof and walls varied from a minimum of 2 in. in the southwest corner to a maximum of 6-1/4 in. in the northeast corner. Figure 4.8 shows the movement at the center of the room, where the upper part of the shelter was moved 4-1/4 in. away from ground zero and 4-3/16 in. downward, relative to the "fixed" vertical post to which the lower part of the damaged deflection gauge was attached. Furthermore, about 15% of the floor area "puffed up" from 2 to 8 in. above its original elevation.

Figure 4.9 shows how the floor "puffed up" about 6 in. in the northeast corner of the shelter in the east entryway; pressurized earth caused some earth to "flow" up into the closed room, in which the measured peak

Fig. 4.8. Movement of upper part of Small-Pole Shelter away from ground zero due to blast effects at 53-psi overpressure range.

Fig. 4.9. "Puffed-up" part of the floor of Small-Pole Shelter due to the start of earth flow under moderately long-duration blast overpressure at the 53-psi overpressure range.

overpressure was only 1.5 psi. About 85% of the floor area was undisturbed, as was the floor in front of the man's hand resting on the cross brace. Neither the blast gauge resting on the brace pole in the corner nor the small expedient fallout meter on top of it was moved.

If a person had been standing on the floor when it was "puffed up" suddenly, possibly his legs could have been injured. To prevent possible injuries due to an intact ceiling moving very rapidly downward and/or the floor moving upward, occupants could recline in expedient bed-sheet hammocks[12] slung from the upper horizontal brace poles of the main shelter room, as shown in Fig. 4.10.

The whole roof, the upper horizontal braces, and the upper ends of the wall poles were all displaced about 4-1/4 in. to the west (away from ground zero) by the blast effects on the 5-ft-high mound of shielding earth over the shelter. The sides of this mound sloped about 36°; its width on top averaged about 10 ft. (If this dry mound had been subjected to the blast effects of a megaton or larger nuclear weapon at the same 53-psi overpressure range, the much greater impulse and longer-duration drag effects might have caused the earth mound to be displaced far enough to wreck the underlying pole shelter — especially since the long-duration blast winds would have scoured away most of the cover of very dry, loose earth. Even a mound of wet earth, which is much less vulnerable to long-duration blast-wind scouring, might have been displaced far enough to cause serious or disastrous structural damage.)

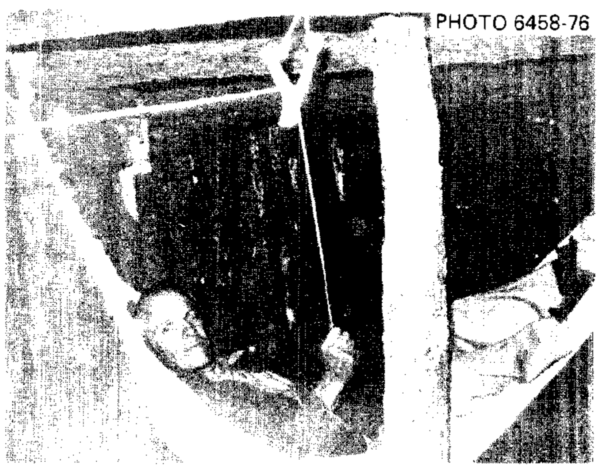

Fig. 4.10. Expedient bed-sheet hammock, useful to avoid severe shock effects in a shelter at high overpressure ranges. The man is operating an expedient shelter ventilating pump via an expedient pulley equivalent, a greased forked stick suspended on strings.

The maximum overpressure measured inside the shelter was 1.5 psi — not enough to be harmful. Less than half of this pressure increase was due to the sudden reduction in the volume of the shelter room which was described above. The rest was caused by blast wind that blew through cracks between the poles near the top of the vertical entryways. These cracks appeared after the initial blast wind had scoured away several inches of the covering earth and torn away the polyethylene film that, with the essential help of small-scale earth arching, had kept earth from being forced between the cracks by the peak overpressure.

There was no damage to any of the life-support equipment in this shelter, except for quickly repairable damage to the expedient shelter ventilating pump (KAP)[13] pictured in Fig. 4.6. (Without the protection of closed blast doors, a KAP or any other pump securely installed in an entry would be wrecked by the entering shock wave and blast winds, even at ranges as low as 3 to 4 psi. Without forced ventilation, below-ground shelters cannot be fully occupied in warm or hot weather. However, a KAP can be installed so that a shelter occupant can detach it and move it out of the way in the few seconds between seeing the very bright light from a large nuclear explosion and the arrival of the shock wave at lower overpressure ranges.[13])

4.4 Conclusions and Recommendations

4.4.1. A Small-Pole Shelter built in stable ground and equipped with blast doors can give reliable protection against the blast effects of small tactical weapons up to about the 50-psi overpressure range.

4.4.2. A modification of this shelter with a continuous pole floor under the wall poles should not fail as a possible result of a large amount of pressurized and destabilized earth flowing up into it through its floor when subjected to the long-duration overpressures and large movements caused by a megaton explosion.

4.4.3. In order to prevent the above modification from seriously reducing the capability of the shelter frame to yield under blast loading and thus promote protective earth arching, a Small-Pole Shelter should be blast tested with all its poles covered with readily crushable material, such as small tree limbs. Then this material should be covered with fabric or plastic before placing earth around and over the protected shelter.

4.4.4. Small-Pole Shelters modified in these ways should be subjected to the effects of blast simulating at least a 100-kiloton explosion at the 50- and 100-psi overpressure ranges, when installed in a trench dug in unstable earth, deep enough so that its blast doors are only about a foot above the original ground level.

5. UNMODIFIED RUSSIAN POLE-COVERED TRENCH SHELTERS AT 20 AND 6.7 psi

5.1 Purpose

Two identical unmodified Russian Pole-Covered Trench Shelters were tested at the 6.7- and 20-psi overpressure ranges, in order to make a more accurate estimate of the blast protection afforded occupants of this common type of Russian expedient shelter. This unshored "dugout" is recommended for construction in stable earth.

5.2 Construction

The two unmodified Russian Pole-Covered Trench Shelters were of the design detailed in the 1969 Soviet civil defense handbook[14] except that the entrance stairways were at right angles to their lengths, a modification recommended in both the 1972 and 1976 Russian shelter-building manuals.[15,16] Figure 5.1 shows most of the roof poles in position before

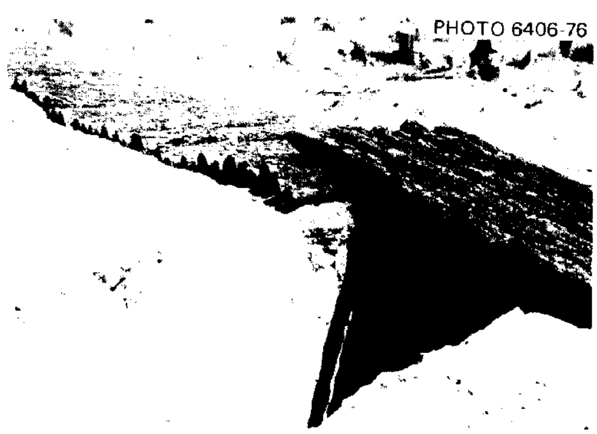

Fig. 5.1. Poles covering Russian Pole-Covered Trench Shelter at 20-psi overpressure range, with uncompleted stairway opening facing away from ground zero.

the shelter was covered with 4-mil polyethylene and with earth mounded 30 in. deep. A total of 62 lodgepole pine poles, each 7 ft long, were laid side by side across the 31-ft-long trench (not including the right-angle entry stairway shown in the foreground of Fig. 5.1). Figure 5.2 gives the details of this simple fallout shelter.

5.3 Location and Test Results

A Soviet civil defense handbook[6] states that within "the zone of complete destruction" the overpressure exceeds 0.5 kg/cm^2 ($\sim$7 psi) and that all residential and industrial buildings and all fallout shelters will be destroyed. (This limitation obviously does not apply to the Russian "hasty shelters" built of prefabricated concrete or steel components. Typical Russian expedient fallout shelters are of light construction and are not designed to withstand blast effects.) Therefore, one unmodified Russion Pole-Covered Trench Shelter was built at the forecast 7-psi overpressure range (6.7 psi was measured). Because of the almost rocklike caliche earth, an identical shelter was built at the 20-psi range, to see if occupants might survive more severe blast effects than those at the 7-psi range. Neither shelter had a blast door.

In the shelter at 20 psi, two anthropomorphic dummies (supplied by the Lovelace Foundation) were seated side by side just inside the inner curtain (see Figs. 5.2 and 5.3). A movie camera was installed by Denver Research Institute for the U.S. Army's Ballistic Research Laboratory. This camera was farther inside the shelter, mounted on a concreted-in-the-ground post. This camera took 400 frames/sec; the four photographs of Fig. 5.3 were taken in 1/100 sec. The first photograph shows only a slight movement of the innermost blanket-curtain. The second shows the earth walls beginning to crumble under the forces of a ground shock wave, induced by the airwave slap overhead before the airborne shock wave reached these walls or the dummies. The third and fourth photographs show the innermost blanket-curtain being torn, revealing the torn outermost curtain, that was darker colored, being blown behind and against it. The collapsing walls trapped the two dummies before the entering blast wind, which was shown by the four movie frames to have a velocity of about 180 mph, could blow them over. (The blast wind peaked at about 470 mph outside this shelter.)

Figure 5.4 shows the dummies trapped by the collapsing walls.

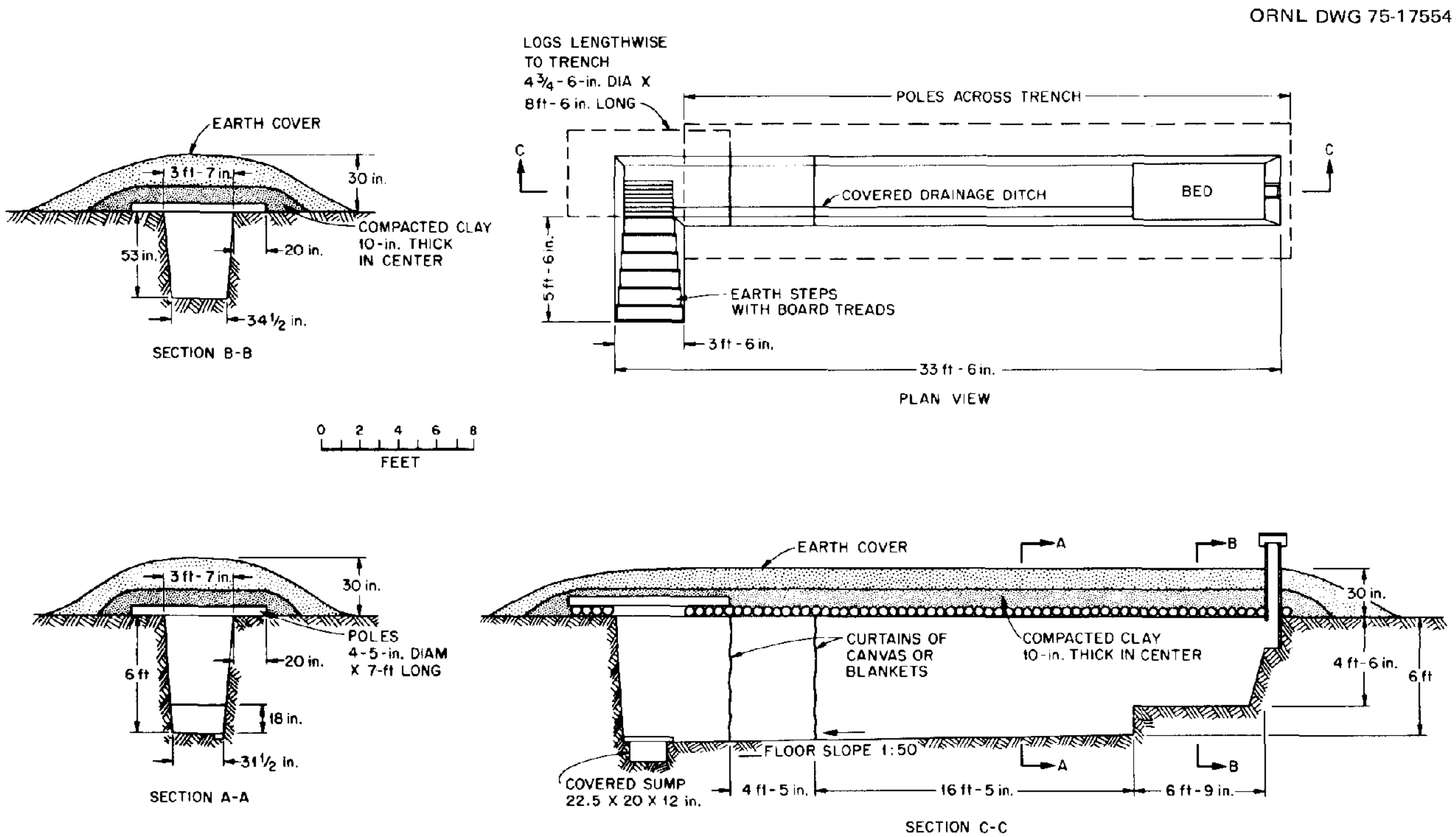

Fig. 5.2. Russian Pole-Covered Trench Shelter in stable earth.

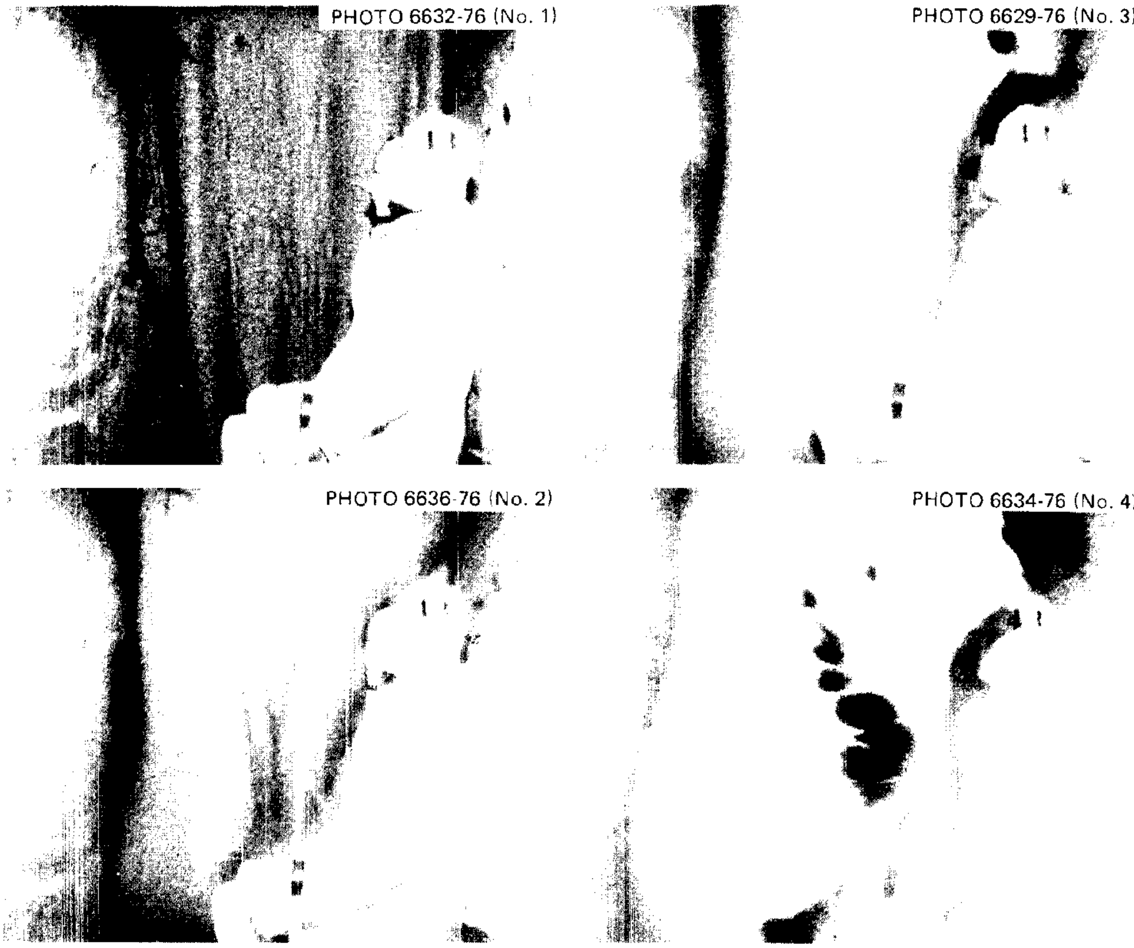

Fig. 5.3. Dummies being struck by air blast and curtains traveling about 180 mph. Note the walls collapsing under ground-shock stresses before the arrival of the airborne shock wave.

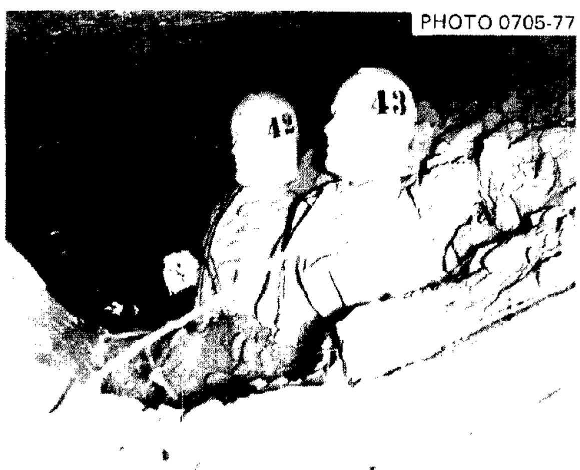

Fig. 5.4. Dummies at 20-psi range after ground shock collapsed the earth walls of shelter. Their steel "bones" and joints prevented them from being knocked down and buried.

Because their strong steel joints did not permit these dummies to bend forward, the collapsing walls did not bend them forward, knock them down, and bury them, as would have been the fate of two men. Note the unbroken roof poles.

The measured overpressure inside this shelter was 7 psi — high enough to break some persons' eardrums. (If this shelter had been subjected to the blast effects of a megaton weapon at the 20-psi range, the maximum overpressure inside the shelter would have been almost 20 psi.)

The entry was wrecked and much of its covering earth was blown away, as illustrated by Fig. 5.5. The ventilation duct was broken off.

Fig. 5.5. Wrecked entry of Russian Pole-Covered Trench Shelter at 20 psi.

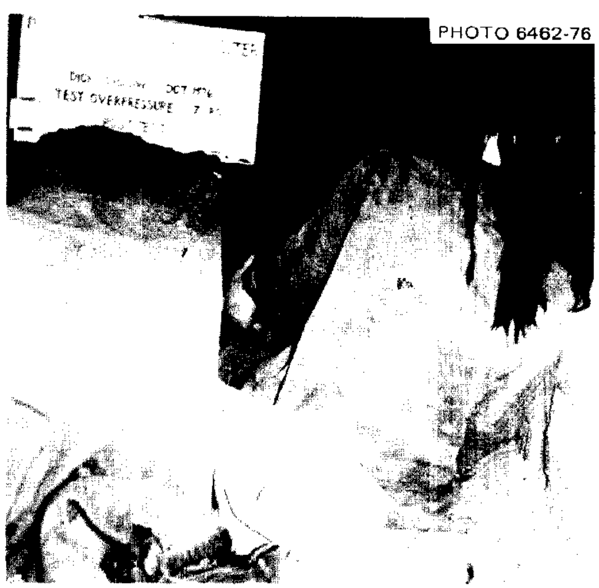

Fig. 5.6. Dummy knocked off bench in Russian Pole-Covered Trench Shelter at the 6.7-psi overpressure range.

At the 6.7-psi range, an identical shelter suffered serious damage. Chunks of hard caliche weighing up to about 400 lb were broken off the very stable earth walls and would have injured shelter occupants. A dummy seated on a fixed bench next to the blanket-curtains was knocked off the bench by the shock wave and the entering blast winds (see Fig. 5.6).

5.4 Conclusions

5.4.1. In soils typical of most inhabited areas, if a shelter of this design were subjected to the blast effects of a much larger explosion at the 7-psi overpressure range, the Russian estimate of "total destruction" would probably prove to be realistic. As specified for Russian shelters, this shelter room and entryway are of stand-up height. (The authors believe that "total destruction" in this sense means the shelter would be so badly damaged as to be uninhabitable — not that all occupants would be promptly killed.)

5.4.2. Earth arching in adequately thick earth cover over pole roofs prevents the poles from being broken by overpressures far in excess of the pressures such roofs could withstand if uncovered.

5.4.3. Stresses due to ground shocks and earth waves would be the predominant causes of failure of unshored trench shelters subjected to the blast effects of large explosions.

5.4.4. To reduce the damage to unshored trench walls caused by the vertical pressures exerted by the roof poles on the trench walls, whenever boards are available they should be laid on the ground to serve as mud sills supporting the roof poles close to their ends. (In DNA's MIXED COMPANY blast test,[1] an ORNL Pole-Covered Trench Shelter was essentially undamaged after being tested closed at the 12-psi overpressure range. This shelter was 54 in. deep, 42 in. wide, and had 7-ft roof poles resting on 2 × 6 in. mud sills. However, in MIXED COMPANY the ground-shock effects were not as severe as in DICE THROW.)

6. LOG-COVERED TRENCH SHELTER AT 53 psi

6.1 Purpose

We constructed an unshored trench shelter with its roof poles positioned in two different ways and located at the predicted 50-psi overpressure range because:

1. We anticipated that the extremely stable, rocklike caliche at the test site would result in unshored trench walls being so strong that they would not collapse under the ground-shock stresses produced at the 50-psi range by 1-kiloton blast effects.
2. We were confident that effective earth arching in the thick earth covering would prevent the breaking of roof poles.
3. We were interested in comparing the effectiveness of the Russian and the Chinese way of roofing a trench with poles or logs.

6.2 Construction

This shelter was built with half of its 12-ft-long room having its roof poles positioned in the Russian manner at ground level (see Figs. 5.1, 5.2, and 6.1). The other half of the room had its roof poles positioned in a recommended Chinese manner[17] (i.e., about 28 in. below ground level). Figure 6.1 shows the vertical cross sections of these

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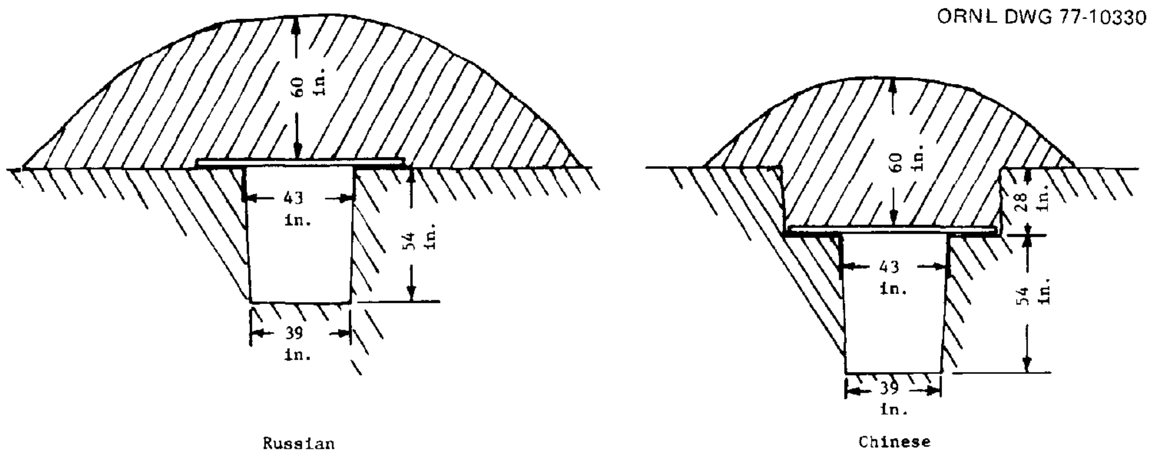

Fig. 6.1. Comparison of Russian way and Chinese way of positioning poles to roof a trench shelter. Note that the Chinese way requires about 35% less earth to be moved in order to make a 5-ft-thick covering – about the thickness specified in a Chinese handbook for shielding against initial nuclear radiation.

two halves as modified from the original designs in order to permit a better comparison between the merits of the two different ways of positioning roof poles. (The room of the Russian half was made 16 in. less in height than in the original Russian design, and the Chinese half was made 4 in. less in width than specified in the Chinese handbook.[17])

As shown in Fig. 6.1, the Chinese half was built with its roof poles resting on earth shelves 28 in. below ground level, cut into the hard caliche. All roof poles (logs) were ponderosa pine. The poles averaged about 5 in. in diameter, not including their bark; all were cut 7 ft long. Earth was mounded about 5 ft above ground level over this whole shelter. This resulted in about 4-1/2 ft of earth covering the roof logs of the Russian half and about 6 ft covering the roof logs of the Chinese half. Blast-wind scouring removed a foot of this mounded dry, loose earth. If blast-wind scouring by a very large explosion had blown away almost all the dry earth mounded above ground level, the Chinese shelter would still have had adequate cover to provide good fallout protection.

The vertical parts of the two entries to the shelter were of a newly developed design with triangular cross sections. The expedient blast doors were of a new triangular type. This design (see Figs. 6.2 and 6.3) was developed in order to: (1) use green poles cut from

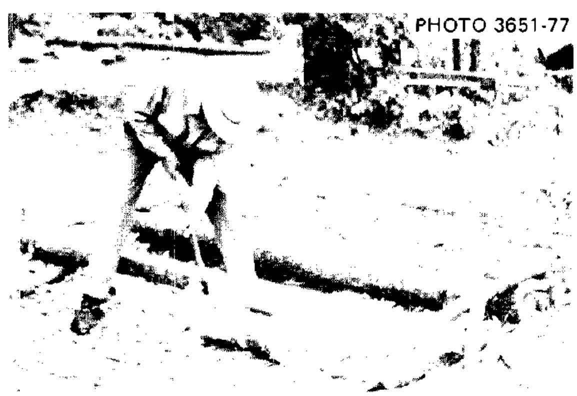

Fig. 6.2. Hewing square sides on a log. The hewer had first secured the log by nailing two small poles to the unhewn logs on the ground and to the already hewn upper side of the log, near its ends. Then he had made vertical ax cuts about 3 to 4 in. apart and at angles of about 45° to the surface of the log. He had made these multiple cuts almost as deep as he planned to make the centerline of the finished flat side. The hewer is shown cutting off long strips, producing a vertical flat side at right angles to the already hewn, horizontal upper side.

PHOTO 0700-77

Fig. 6.3. Expedient triangular blast door made of pine poles. The auto-tire flap valves over the 1-1/2-in.-wide spaces between the poles were undamaged by the blast effects at the 53-psi overpressure range. Ground zero was to the left, in prolongation with the hinge pole of the door. Blast effects had moved the three connected blast-protector logs, preventing the door from being opened fully.

ordinary trees to make a tight-closing expedient blast door that takes advantage of the fact that three intersecting straight lines determine a plane, (2) require only widely available hand tools and common materials (e.g., auto tires, nails, and some wire or rope, in addition to poles), and (3) make practical the use of a triangular vertical shelter entry, which has a smaller cross-sectional area than does a rectangular vertical entry big enough for the same sized person to use and shows promise of requiring less materials to meet a given level of blast protection.

Few modern Americans know how to hew flat sides on a log or pole, a skill required to build blast-tight blast doors out of green trees. But most persons who can swing an ax should be able to learn quickly if shown instructions for hewing such as those given in Fig. 6.2.

The triangular blast doors tested at 53 psi are shown in Figs. 6.3, 6.4, 6.5, and 6.6.

PHOTO 6442-76

Fig. 6.4. View of the same triangular blast door, looking in a direction perpendicular to the radius from ground zero. The hinge pole, originally 7 in. in diameter after peeling, had been flattened on its top and back side. The two other poles, 8 in. in diameter, had been flattened on their bottom, top, and inner sides. All three outer poles were notched and nailed together. Note the slots between the door-covering poles.

PHOTO 6443-76

Fig. 6.5. Broken pole of triangular door seat. This pole was broken by differential movements of the earth mounded over the shelter. The man's hand rested on the unbroken hinge pole.

Fig. 6.6. Posttest condition of expedient triangular blast door. Some flap valves had been jammed shut, and much earth and sand had been deposited.

6.3 Test Results

Figures 6.2 and 6.3 show the triangular blast door on the south end of the shelter, undamaged after the blast. Note that one of the three blast-protector logs (the log in the lower left corner of the photograph) has been pushed by the blast up against the hinge pole of the blast door. The door was undamaged. (If a door of this type and size was not protected by blast-protector logs and if at the 53-psi overpressure range a blast shock wave struck one of its 8-in.-thick edges perpendicular to the plane of this edge, the door could be subjected to a peak horizontal force of about 90 tons.) However, the movement of the earth mound had broken the door-seat pole on which the man's foot is shown resting in Fig. 6.3. Figure 6.5 shows the break more clearly.

Both of the triangular blast doors were undamaged. The expedient blast valves on the blast doors were closed by the blast, and about 75% opened after the blast, permitting adequate ventilation with an expedient pump, a KAP. The overpressure inside the Chinese half was 1.5 psi, and the overpressure directly under the north door was 3 psi. The results of this test indicate that the use of expedient blast valves over the 1-1/2-in.-wide cracks of this blast door is impractical. Most of the flap valves opened before the strong blast after-winds subsided. These winds plus the natural desert winds blew so much dirt and sand through the valves and into the shelter that a serious fallout entry problem could exist after a nuclear blast. Figure 6.5 shows the blast door at the north end of the shelter before it was opened after the blast. Much earth and sand had been deposited on it by the subsiding blast winds.

Although not one roof pole of any part of this shelter or any other shelter was broken or cracked, the ground-shock effects collapsed the walls of the Russian half of this shelter so badly (see Fig. 6.7) that all occupants would have been killed. Damage to the Chinese half was much less serious, although hundreds of pounds of caliche, some chunks weighing up to 20 lb, were broken off the edges of the shelves supporting the roof logs. The roof deflection gauge in the Chinese half recorded a maximum transient downward deflection of 1-1/2 in. and a permanent deflection of 7/8 in.

Fig. 6.7. Postshot view of the caved-in caliche walls of the "Russian" half of the Log-Covered Trench Shelter at 53 psi.

6.4 Conclusions and Recommendations

6.4.1. Under the longer-duration blast effects of a large nuclear explosion, vertical entries protected by steep-sided earth mounds rising several feet above original grade level would probably be wrecked by the combined effects of blast-wind scouring and dynamic drag.

6.4.2. Blast doors should be positioned only about a foot above ground level, and earth should be mounded with slopes of 10° or less.

(Unfortunately, such deeper excavation, even in softer earth, might make construction within 48 hr impractical for builders having only hand tools.)

6.4.3. Triangular blast doors made of poles can readily be built to withstand 50-psi blast effects, but should be made solid and as nearly dust-tight as practical. Separate ventilation shafts with blast valves should be provided, with the blast valves positioned about 2 ft from the bottom of each shaft.

6.4.4. Persons building expedient shelters to provide protection against nuclear blast effects should build well-shored shelters with blast doors and blast valves whenever practical.

7. LOG-COVERED TRENCH SHELTER AT 31 psi

7.1 Purpose

A near counterpart of the Log-Covered Trench Shelter that was tested at 53 psi was tested at 31 psi, in order to determine at what overpressure range this type of shelter, if built in extremely stable earth, will survive. Also we wished to test a semiexpedient design of steel blast door on a shelter entrance at approximately 30 psi.

7.2 Construction

This shelter was constructed the same as the Log-Covered Trench Shelter at 53 psi, except that protecting its single entry it had a semiexpedient blast door made of about 65% of a 30-gal steel oil drum. Rubber-tire hinges and rubber-tire seals made a snug closure between the door and the upper part of the vertical entry. The upper 2 ft of the vertical entry was made of two thicknesses of 2-in. boards nailed together (see Fig. 7.1).

7.3 Test Results

Although the blast effects loosened some of the bolts of the steel blast door, tore the metal in several places, and produced other damage indicating that it was on the verge of failure, it did not fail.

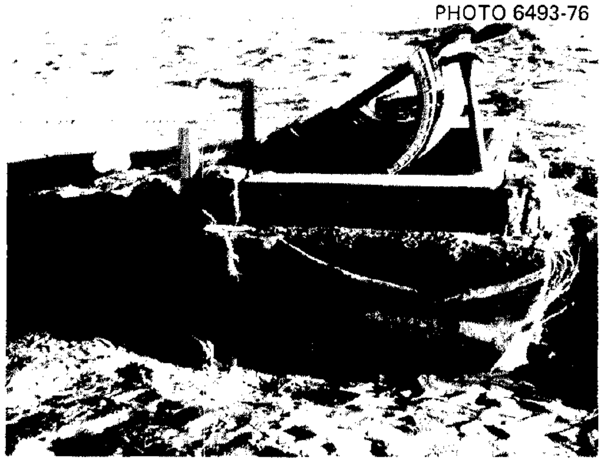

Fig. 7.1. Semiexpedient blast door made of a 30-gal steel drum, badly damaged at 31 psi but still blast-tight. Blast-wind scouring had removed up to 17 in. of the dry earth mounded around this entrance and blown away its single blast-protector log.

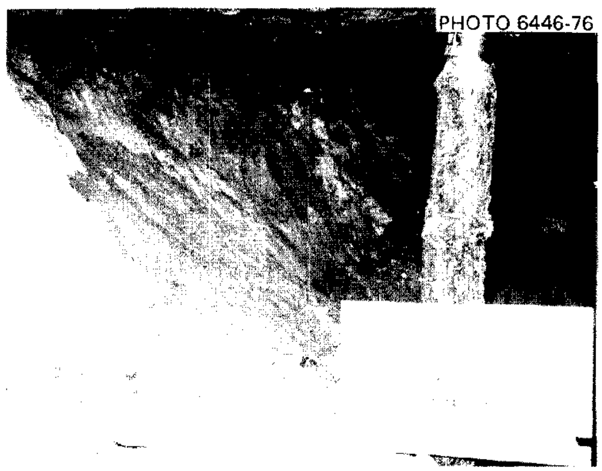

Fig. 7.2. Serious wall caving at 31 psi (predicted 30 psi). The beam deflection gauge on top of the post showed a 2-1/2-in. lowering of the center roof log.

Figure 7.2 pictures the interior of the Chinese half of the shelter after the blast had broken hundreds of pounds of caliche off the very stable walls and lowered the roof poles from an estimated maximum of up to 6 in. at some lower ends on the side nearest ground zero to a minimum of about an inch at some of their opposite ends. This lowering did not cause the roof to collapse. No poles were cracked in any part of this shelter. The walls of the Russian half collapsed so badly that all occupants would have been buried.

7.4 Conclusion and Recommendations

7.4.1. Even in extremely stable earth, an unshored trench shelter at 31 psi would give inadequate blast protection against even a small tactical nuclear weapon.

7.4.2. The steel-drum blast door is not as blast resistant as pole or plywood blast doors that require materials much less difficult to find and that require less skill, tools, and time to build.

8. DOOR-COVERED EARTH-ROLL SHELTERS AT 15 AND 5.8 psi

8.1 Purpose

Two of these aboveground small fallout shelters,[7] made of interior hollow-core doors, bed sheets, and other materials available in tens of millions of American homes, were tested at the 15- and 5.8-psi overpressure ranges in order to determine whether the shelters would afford better blast protection than would typical homes.

8.2 Construction

Each shelter was built with its long axis on a radius from ground zero. Figure 8.1 shows the interior of the shelter at the 15-psi range before the explosion. The vertical stick touching a roofing door is a

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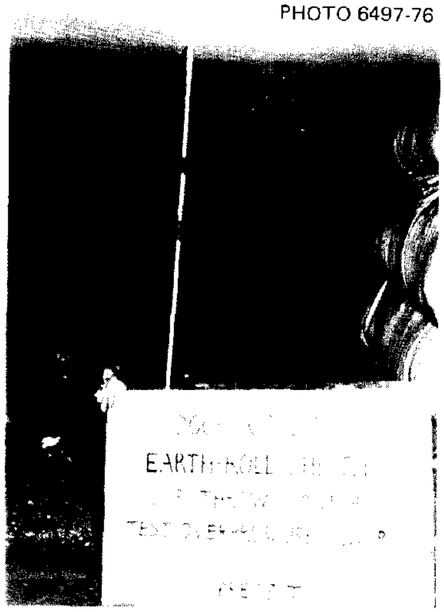

Fig. 8.1. Bed-sheet "earth-roll" walls 36 in. apart before test.

roof deflection gauge, with its upper end consisting of nothing but a thin cylinder of household aluminum foil, an unsatisfactory device if exposed to blast wind. Figure 8.2 gives details of the construction of these shelters.

8.3 Test Results

Figure 8.3 is a posttest picture of the northward-facing entry of the shelter at the 15-psi overpressure range. This photograph also shows part of the northward-facing side of this shelter. The blast winds scoured only about 1 in. of earth from the top of this shelter, apparently because its long, flat top extended in the same direction that the blast winds blew. Note the proof of the toughness of polyester-cotton pillowcases used to make 100-lb sandbags. The sandbag in the foreground was blow about 7 ft by the approximately 370-mph blast wind without being broken.

To the surprise of most observers, earth arching above the roof doors prevented any of them from being broken in by the blast effects. The doors were not broken in, even though the lower 1/8-in. plywood veneer of three of the six doors was broken. Figure 8.4 pictures the interior of the shelter at the 15-psi overpressure range after the blast effects outside had caused the sandy soil inside the bedsheet "earth-rolls" to "flow" inward rapidly. The width of the shelter was reduced from 36 in. to a minimum of 14 in. No additional earth movements were observed during the two weeks following this test. This unanticipated earth "flow" within the "earth-rolls" did not tear any of the pieces of bedsheet cloth. The velocity of earth "flow" was not measured. However, we believe that such earth "flows" take place only while earth is destabilized by ground-shock effects. Judging from the pressure-time measurements cited in the following paragraph, the drastic reduction in the width of this shelter occurred in less than a second — too short a time to permit a shelter occupant sitting with back against a wall to avoid being crushed.

Pressure-time measurements on the adjacent DNA Gauge Line No. 1 showed that only about 40 msec elapsed between the peak overpressure of 14.9 psi recorded at the same distance (820 ft) from ground zero, and

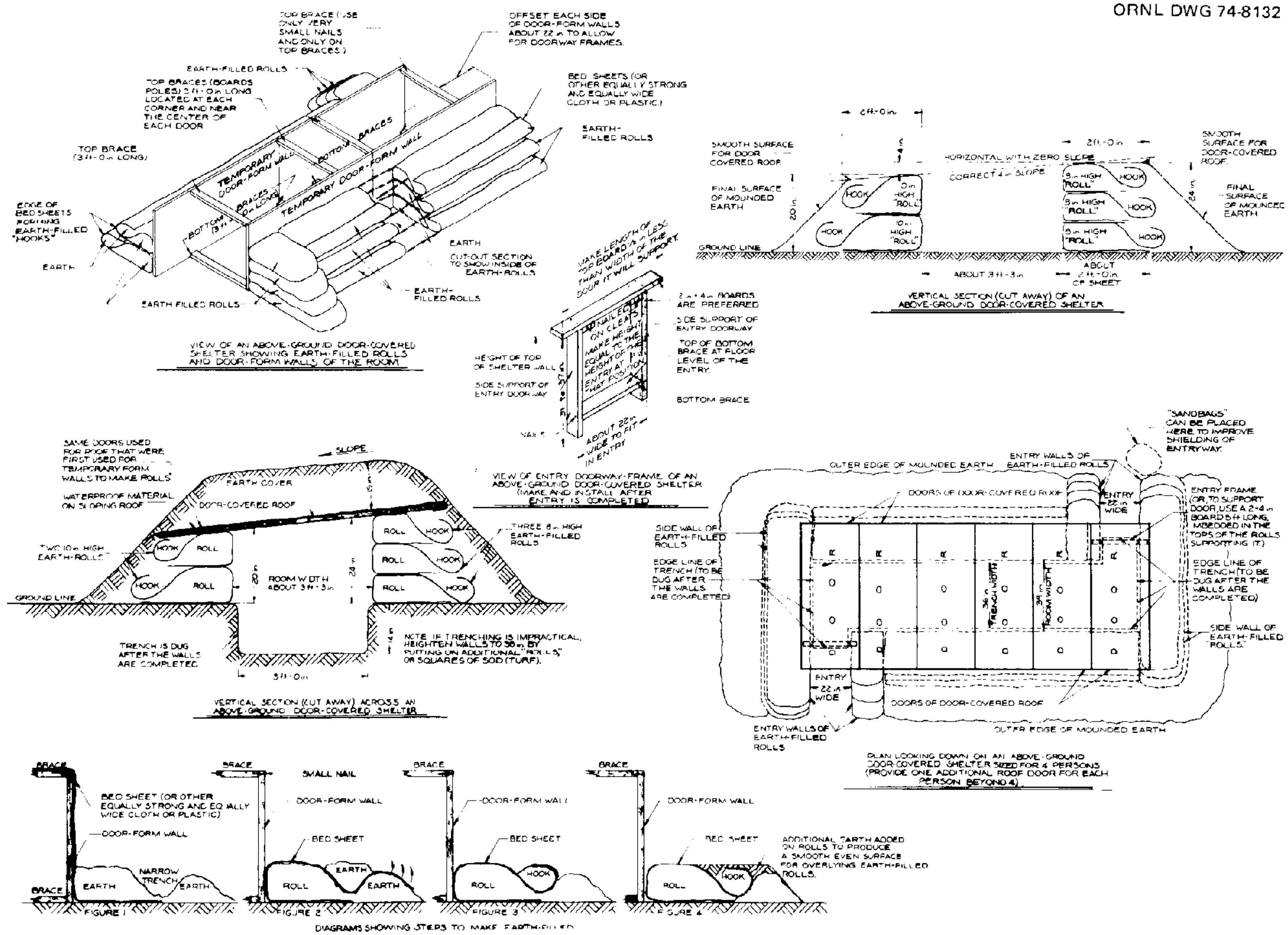

Fig. 8.2. Door-Covered Earth-Roll Shelter, tested at 15 and 5.8 psi.

PHOTO 6483-76

Fig. 8.3. Northward-facing entry (at right angle to the direction to ground zero) of Door-Covered Earth-Roll Shelter at the 15-psi overpressure range. This is a posttest photograph.

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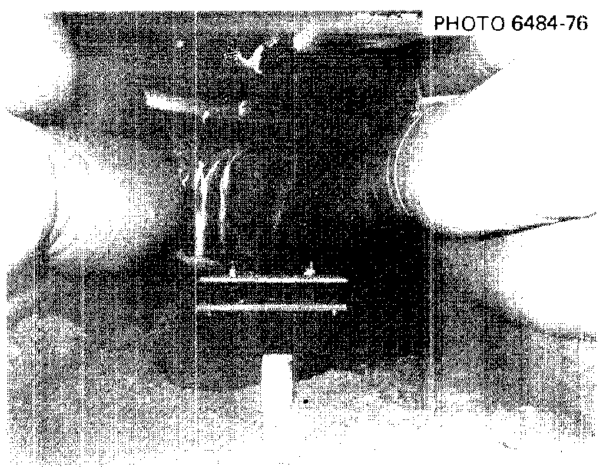

Fig. 8.4. Interior of Door-Covered Earth-Roll Shelter after 15-psi blast effects had reduced width of shelter from 36 in. to a minimum of 14 in. near its center.

its reduction to 6 psi, the maximum overpressure recorded inside this shelter by the ORNL pressure gauge shown in the foreground of Fig. 8.4. The gauge that had been installed to measure the roof deflection was blown away by the entering shockwave and blast wind. The reduction in ceiling height appeared to be less than 1 in. in this part of the shelter, but up to about 4 in. in other parts.

At the 5.8-psi overpressure range, the Door-Covered Earth-Roll Shelter was still habitable for weeks after the test. Figure 8.5

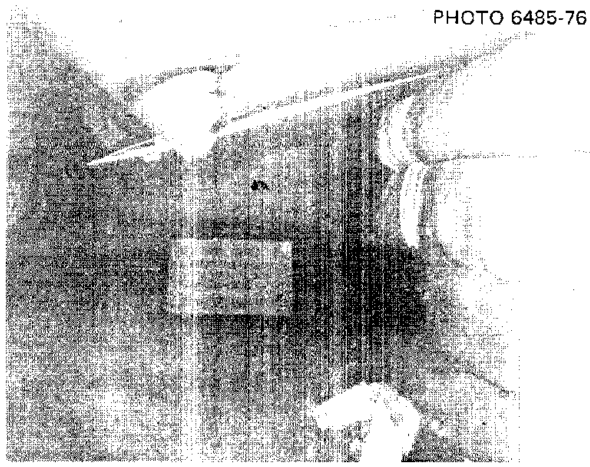

Fig. 8.5. Posttest interior of Door-Covered Earth-Roll Shelter at 5.8-psi overpressure range. The lower 1/8-in. veneer of the doors had been badly broken by impact before the test, due to a front-end loader having dumped tons of earth onto this yielding roof.

shows that at 5.8 psi the walls were not forced inward by the blast effects. The unbroken upper 1/8-in. veneer plies of the doors held as flexible membranes, and earth arching was set up in time to prevent this shelter's roof from being collapsed either as a result of initial mechanized earth loading or due to the 5.8-psi blast effects.

The peak overpressure measured inside this shelter was 3 psi, about half the 5.8 psi measured outside on DNA's adjacent Gauge Line No. 1. The blast winds, which peaked outside at about 175 mph, scoured away only a fraction of an inch of the shielding earth.

8.4 Conclusions and Recommendations

8.4.1. A Door-Covered Earth-Roll Shelter obviously is impractical for use as a blast-protective shelter against blast effects considerably less than those at the 15-psi overpressure range from even a very small nuclear weapon.

8.4.2. If this fallout shelter with a protection factor of at least 200 had been built in a typical suburb and had been subjected to the blast winds from a megaton weapon at the same 5.8-psi overpressure range, it might have been damaged or destroyed by blast-hurled pieces of houses and/or trees.

8.4.3. Notwithstanding the hazards inherent in the use of this or any other lightly constructed aboveground shelter in a blast area, occupants of this simple shelter would have a decidedly better chance of surviving than would people inside typical suburban homes, which would be demolished by the blast effects at 5.8 psi.

9. RIDGE-POLE SHELTERS AT 15 AND 5.8 psi

9.1 Purpose

In wooded areas having the water table or rock too close to the surface for below-ground expedient shelters to be practical, untrained families with few tools have been able to build Ridge-Pole Shelters in less than 48 hr.[12] No prior blast testing of this type of shelter, which has its side poles merely leaning against its ridge pole, had been carried out anywhere (see Fig. 9.1).

9.2 Construction

Two identical Ridge-Pole Shelters were built, each having the dimensions shown in Fig. 9.2. One was tested at the measured 15-psi overpressure range and the other at the 5.8-psi overpressure range. Each was positioned with its ridge pole perpendicular to a radius from ground zero, with one of its two crawl-in entries facing ground zero

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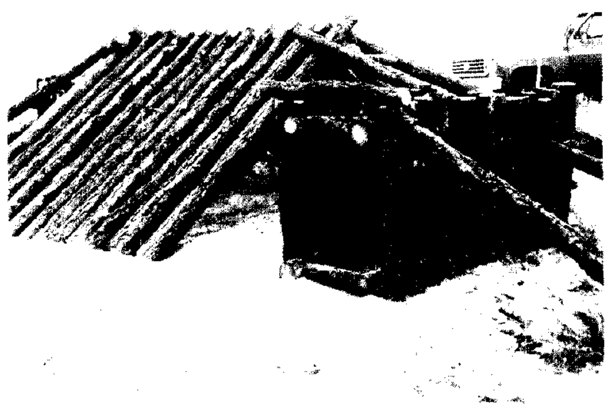

Fig. 9.1. Almost completed frame of Ridge-Pole Shelter at 15 psi. Only the outermost roof pole of the entry had been placed on its wall poles.

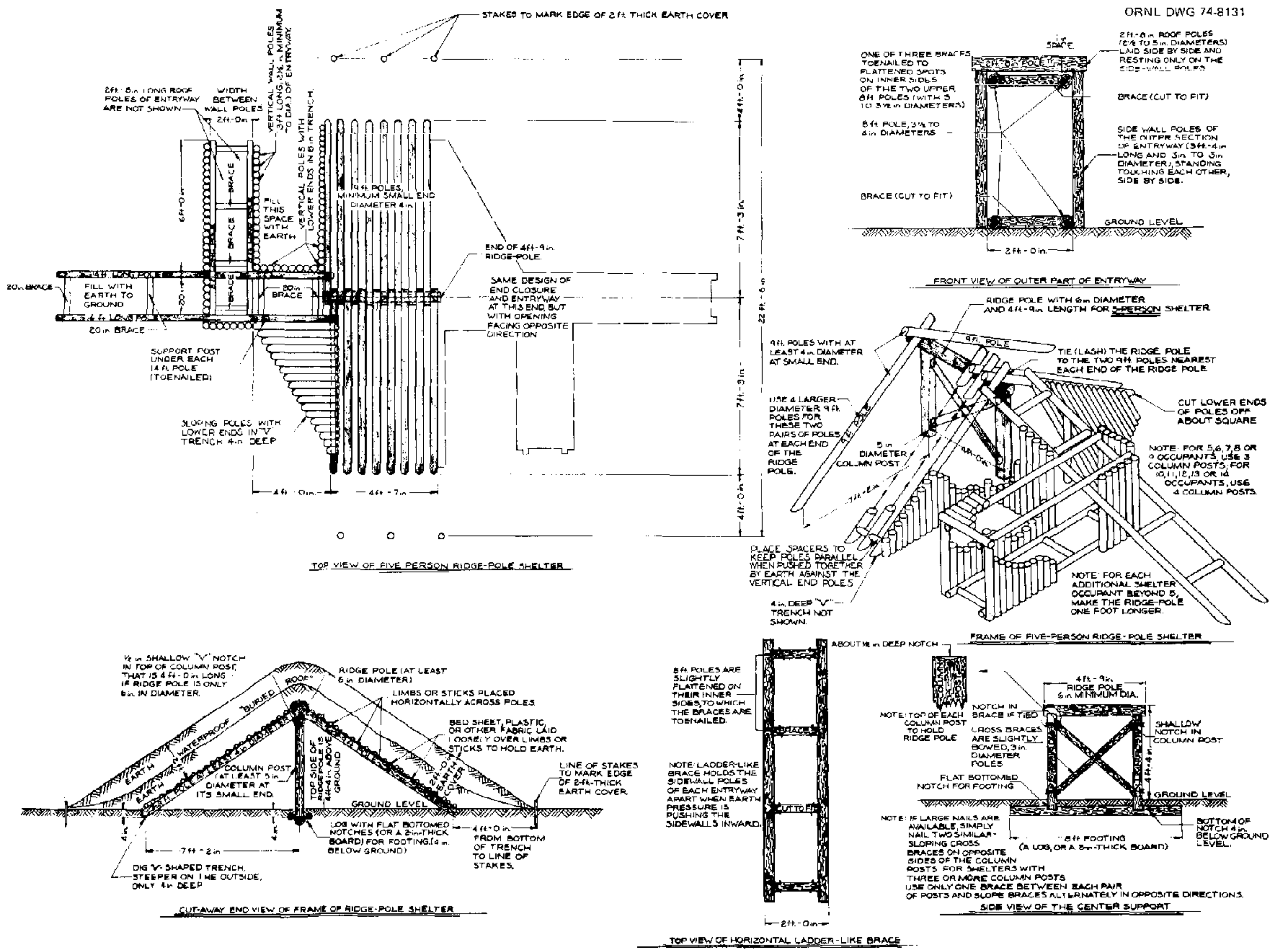

Fig. 9.2. Ridge-Pole Shelter tested at 15 and 5.8 psi.

and the other entry facing in the opposite direction. Figure 9.1 shows the almost completed pole frame, plus a temporary brace pole steadying the entrance. The pole frame was next covered with small, leafy limbs (Fig. 9.3), which in turn were covered with 4-mil polyethylene. Then a covering of dry, sandy earth 2 ft thick was placed over the whole shelter, with earth-filled potato bags retaining the earth over the entrances.

PHOTO 6476-76

Fig. 9.3. Covering the frame of a Ridge-Pole Shelter with salt cedar limbs.

9.3 Test Results

9.3.1 At 15 psi. Contrary to our expectations that the blast effects would collapse the main room, the main room was undamaged (see Fig. 9.4). The ridge pole was moved only 3/4 in. away from ground zero. However, up to 9 in. of earth was scoured off the top of the shelter. In three places the underlying plastic over the ridge was broken; as a result, dry, sandy earth fell through the roof poles in these places, producing holes several inches across, open to the sky.

The seriousness of what would be the amount of blast-wind scouring by a 1-megaton explosion (which at a given overpressure range would produce blast winds lasting ten times as long as the 1-kiloton blast winds at DICE THROW) is indicated by the removal of all shielding earth from the ground-zero side of a 1/10-scale model of this Ridge-Pole Shelter, also tested at 15 psi (see Fig. 9.5).

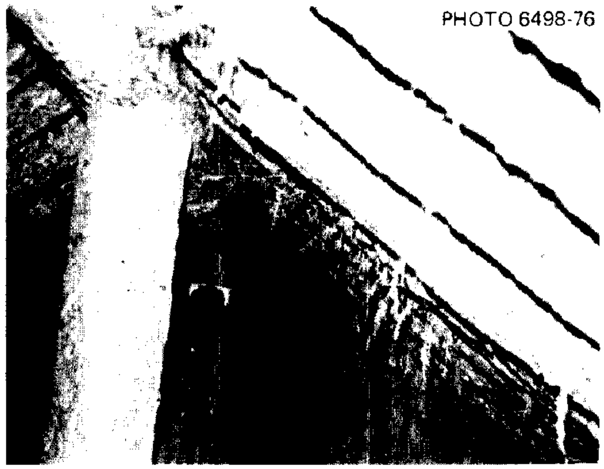

Fig. 9.4. Posttest interior of Ridge-Pole Shelter at 15 psi. The main room was undamaged; the ridge pole had been moved only 3/4 in. away from ground zero.

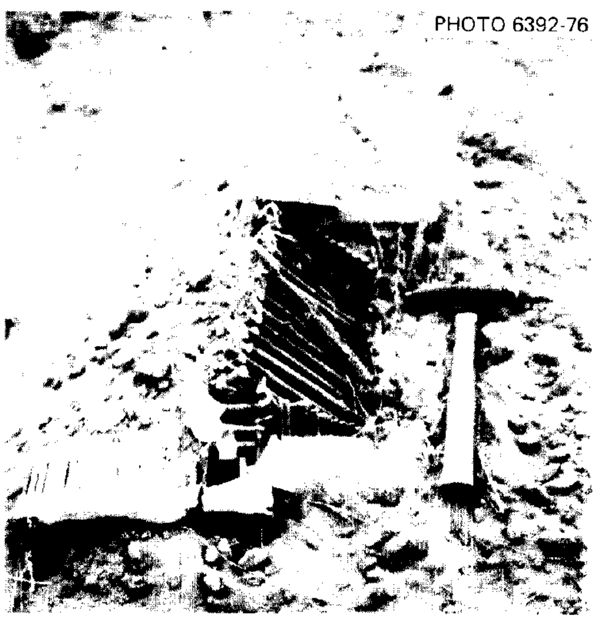

Fig. 9.5. Posttest exterior of 1/10-scale Ridge-Pole Shelter at 15 psi. Scouring by the blast winds had removed practically all the earth, plastic, and twigs on the side facing ground zero and over the two entries — indicative of blast-wind scouring of earth cover over a full-scale shelter by a megaton explosion.

The most surprising damage is shown by Figs. 9.6 and 9.7. Obviously, the dry earth moved ("flowed") away from the middle of the shelter and toward the two ends of the shelter. Apparently the pressures on the ends of the shelter were decreased as compared with the pressures on the

PHOTO 6478-76

Fig. 9.6. Collapsed entrance facing away from ground zero, at 15 psi. The blast winds had scoured away most of the covering earth, and the earth had "flowed" away from the center of the shelter, pushing the upper part of the entry in a direction perpendicular to the radius from ground zero.

PHOTO 6477-76

Fig. 9.7. Postblast view of the entry of the Ridge-Pole Shelter facing ground zero, at 15 psi. Note the scattered potato-sack sand-bags that had been placed to retain the earth over the entry. Earth "flow" had pushed all but the base of the entry away from the middle of the shelter, leaving none of the entry walls perpendicular.

center, both by the lack of reflected overpressures at the ends and the lowering of pressures at the ends caused by Bernouli effects, where the velocities of the blast winds were increased as the winds passed around the ends of the obstructing shelter.

The three fireplace-size logs (see Fig. 9.7) in front of the entrance facing ground zero, and also the two poles pictured resting on the side of the shelter, had been carried by the blast winds from where they had been stacked before the test at the 70-psi range, 315 ft from where they came to rest. Note the identifying spot of paint on the end of the log on the right.

The overpressure inside reached only 3 psi, due to the small size of the semicollapsed entryways, the relatively large volume of the main room, and the relatively short time (about 80 msec) that the overpressure outside remained above 3 psi.

9.3.2 At 5.8 psi. As anticipated, this Ridge-Pole Shelter was undamaged as regards its pole frame. Measurements showed the ridge pole to be unmoved. However, 6 to 12 in. of dry, sandy earth was removed from the ridge, partly due to blast-wind scouring and partly due to shock effects having broken five holes in the 4-mil polyethylene where the thin plastic covered the rough ends of the wall poles. Some dry, sandy earth had fallen through these holes, but no part of the roof was wholly uncovered. The overpressure measured inside was 2 psi.

9.4 Conclusions and Recommendations

9.4.1. Due to the amount of dry shielding earth that would be removed by the blast winds produced by the sizes of nuclear weapons that menace the United States, and also due to the damage that aboveground shelters built in wooded areas would suffer from blast-hurled trees, the practicality of Ridge-Pole Shelters for protection against both blast effects and fallout is severely limited. (If the earth is wet, however, blast-wind scouring by 1-kiloton blast winds at the 16-psi overpressure range removes a negligible thickness of sandy earth from a shelter with the same slope and orientation of roof.[1])

9.4.2. Before covering this type of shelter with thin plastic preparatory to covering with earth, the ends of its poles should be covered with cloth, rugs, or other stronger material in order to prevent the sharp edges or splinters on the ends of poles from causing the plastic to be torn when being covered with earth or subjected to blast stresses.

10. DOOR-COVERED TRENCH SHELTERS AT 31 AND 15 psi

10.1 Purpose

Most separate American homes have enough interior doors to roof a trench shelter for the occupants and thus provide them with much better protection against fallout radiation and fire than do the great majority of homes. In a prior DNA blast test, a Door-Covered Trench Shelter was essentially undamaged at 5 psi. Therefore, we tested this simple fallout shelter at the predicted 30- and 15-psi overpressure ranges. The test at 30 psi was carried out to learn whether or not earth arching would prevent the collapse of the hollow-core interior doors roofing a trench dug in almost rocklike earth — not to estimate the ultimate survivability of persons exposed to 30-psi blast effects in a very small open shelter.

10.2 Construction

The Door-Covered Trench Shelters at 31 and 15 psi were of identical construction, as shown by Fig. 10.1. However, a greater thickness of earth was mounded over these shelters, about 2-1/2 ft, than shown in this drawing. We found that a hollow-core interior door can withstand being covered with earth many feet thick, since it yields under loading, and protective earth arching develops in earth mounded over it.

10.3 Test Results

10.3.1. The shelter at 31 psi was a total failure. Earth arching over the doors did not prevent them from being broken in at this high overpressure. Figure 10.2 shows the depression resulting from this collapsed shelter, photographed eight days after the blast. Note the large amount of sand that had been blown into this depression during these postblast eight days. In the desert outside the blast-devastated area, the grass and desert shrubs prevented any consequential blowing of sand and dust during these same eight days. Open entries serving as ventilation openings had large amounts of sand blown into them, indicating a potential fallout-entry problem in blast-devastated areas.

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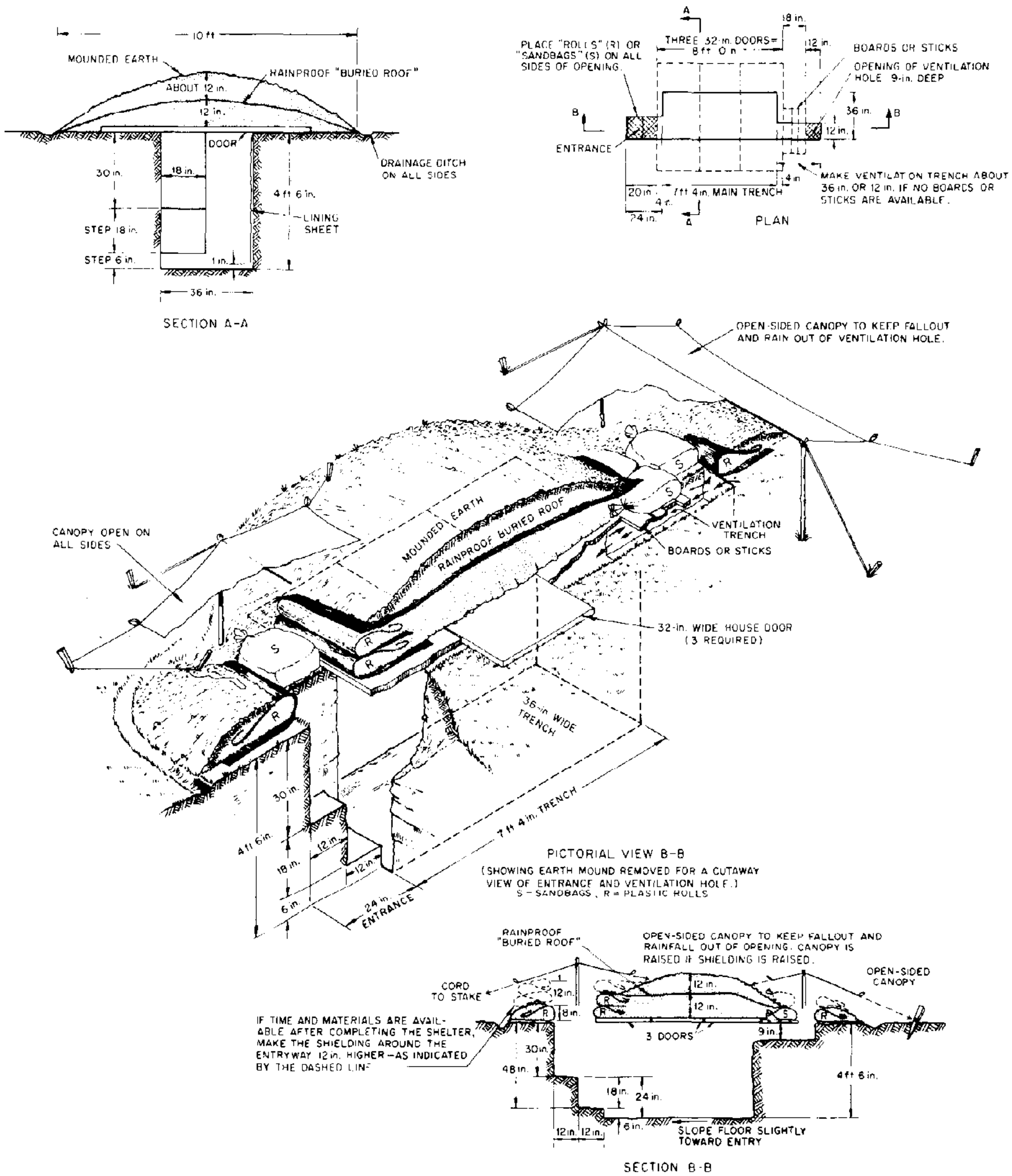

Fig. 10.1. Door-Covered Trench Shelter tested at 31 and 15 psi.

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Fig. 10.2. Photo of Door-Covered Trench Shelter at 31 psi taken eight days after the blast. The doors were smashed in. Note the sand accumulation in the right side of the hole, indicative of the probability of dangerous amounts of fallout being blown into entries used as ventilation openings in blast-devastated areas.

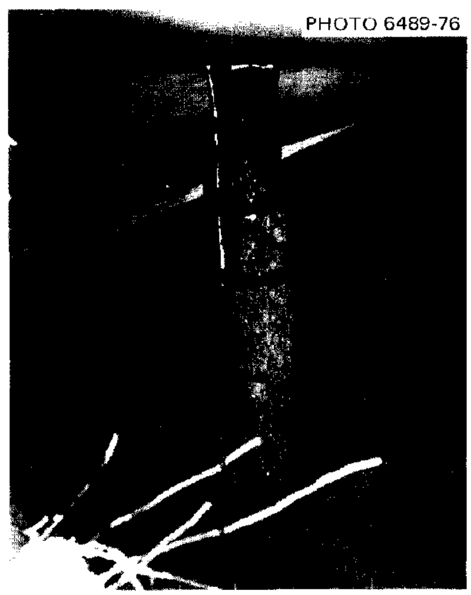

Fig. 10.3. Postblast interior of Door-Covered Trench Shelter at 15 psi. Large chunks of earth were knocked off the walls. Between 16 and 24 days after the blast, the partly broken doors broke completely.

10.3.2. At 15 psi the roofing doors were cracked but not broken in (see Fig. 10.3). However, much hard caliche was broken off the walls. The overpressure measured inside the shelter was 5 psi, high enough to break some occupants' eardrums.

10.4 Conclusions and Recommendations

10.4.1. If subjected to the longer-duration overpressures and greater amplitudes of ground motions caused by strategic weapons, Door-Covered Trench Shelters would afford obviously inadequate blast protection at overpressure ranges considerably less than 15 psi.

10.4.2. In blast-devastated areas, the problem of fallout particles being blown into shelters dependent for their air supply on ground-level openings could be serious.

11. CHINESE "MAN" SHELTER AT 20 psi

11.1 Purpose

In the first Chinese handbook[17] on nuclear defense that came into our hands, we saw the shelter illustrated by Fig. 11.1. Previously, we had never seen or conceived a blast shelter of this design or one built of such thin poles. If such thin poles could safely be used, it would reduce the labor of obtaining the poles for an expedient blast shelter — one of the chief constraints on the practicality of such shelters. Therefore, we decided to blast test this Chinese design.

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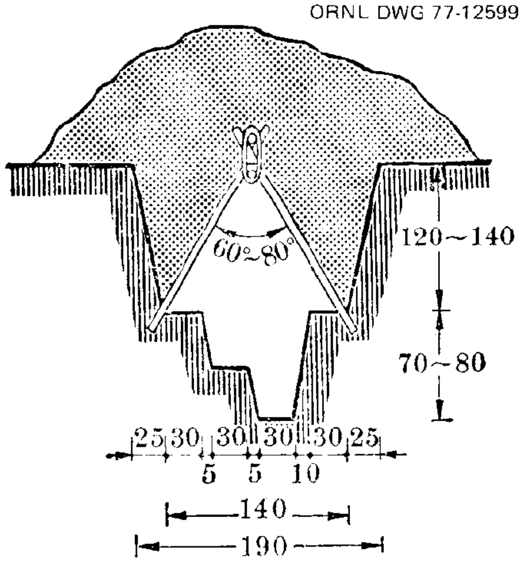

图 3-107 人字形骨架避弹所

Fig. 11.1. Chinese "Man" Shelter tested at 20 psi. This shelter is called "Man" Shelter in a Chinese civil defense handbook because a cross section of its frame resembles the Chinese character "人" for "man."

11.2 Construction

The main room was 10 ft long. It was made in a trench with two shelves, a bench, and a 1-ft-wide foot trench dug into the hard caliche. The sloping wall poles were first cut 6 ft by 6 in. long, but later had to be reduced about 6 in. in length because their lower ends could not have been dug into the rocklike earth without breaking off large chunks of the two shelves on which the wall poles rested. The two small poles, one below and one above where the wall poles crossed at the top of the frame, were encircled tightly with a single strand of No. 9 wire between each adjacent wall pole.

The 10-ft-long main room (see Figs. 11.2 and 11.3) plus a 5-ft-long horizontal entryway required 28 poles on each side, averaging about 3 in. in diameter, including bark. The tops of these poles averaged about 2-1/2 in., excluding bark. The horizontal entryway was of the same design as the main room, except that its entire floor was at the same level as the shelves and the bottoms of the wall poles of the main room. It led to the vertical south-end entry that, for lack of a Chinese drawing, we designed and built using the triangular construction pictured in Figs. 11.2 and 11.4. The poles of the vertical entry averaged a little over 3 in. in diameter, including bark. Above the 30 × 30 in. opening at the outer end of the horizontal entryway, the inside of the vertical entry was an equilateral triangle 39 in. on a side — big

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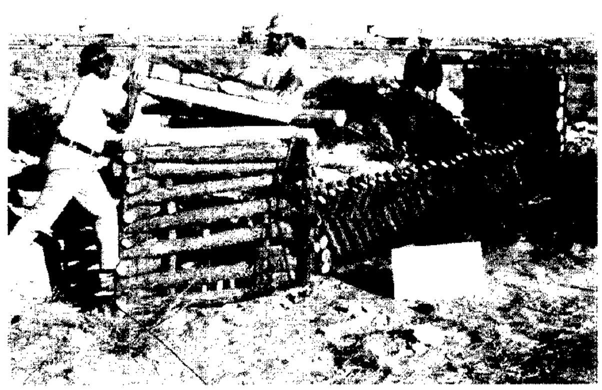

Fig. 11.2. Completed frame of Chinese "Man" Shelter tested at 20 psi. In accord with the Chinese drawing, the poles of the main room averaged only about 3 in. in diameter. The triangular entries and triangular blast doors were of ORNL designs.

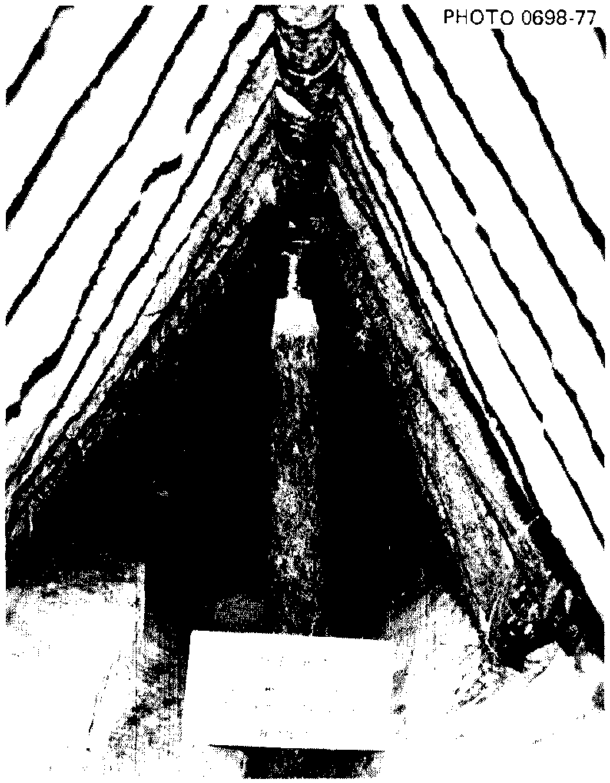

Fig. 11.3. Undamaged interior, showing earth bench on one side and roof deflection gauge on post.

Fig. 11.4. The lower part of the vertical triangular entry is pressed horizontally against two pairs of vertical posts. Each pair is wired together. The two pairs are held apart by two horizontal spacer poles toenailed in place to frame the rectangular opening between the horizontal and vertical parts of the entry. The pairs of vertical posts are pressed against two horizontal poles (the uppermost is shown) that in turn press against both the outermost two poles of the horizontal part of the entry and the earth in two slots dug in the sidewalls of the excavation.

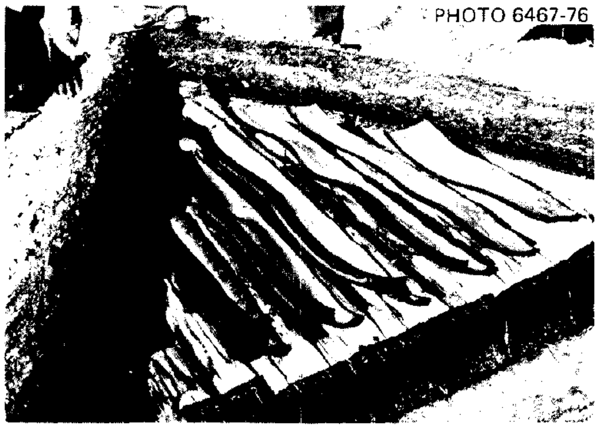

Fig. 11.5. Posttest undamaged triangular blast door, made of three 5-in.-diam peeled poles covered with seven 4-in.-diam peeled poles. Between these covering poles were six 2-in.-wide ventilation slots, protected by six flap valves made of strips cut from worn tire treads.

enough for a big man (see Figs. 11.2 and 11.4). The five uppermost poles averaged 4 in. in diameter, and the top three were notched and nailed together so as to make a plane on which the blast door could be closed snugly.

The blast door was very similar to the triangular blast doors on the Log-Covered Trench Shelters described in Sect. 6, except that the three frame poles of the door were smaller in diameter, and the door had six open slots and six flap valves, as shown in Figs. 11.5 and 11.6. To prevent the door and the uppermost poles of the triangular entry from being pulled up and blown away during the negative pressure phase of an explosion, the uppermost poles were wired securely to poles about 3 ft lower down the entry.

Fig. 11.6. Undamaged triangular blast door, partly open, and viewed looking up the side of the triangular entry to which the door was hinged.

Fig. 11.7. Covering the limb-covered pole frame with bed sheets. Salt cedar limbs had first been placed crosswise over the lightly constructed pole frame.

Figure 11.7 shows the covering of the shelter frame, except for the mounding of the shielding earth. Due to a construction error, the earth was mounded 4 ft deep above the tops of the wall poles, rather than the approximate 3 ft shown by the Chinese drawing.

The outer (north) entry was ruggedly constructed of 6-in.-diam vertical poles, with interior triangular braces. Its blast door was practically identical to the door on the ORNL-designed "Chinese" entry to the south end of the shelter. A rectangular expedient shelter ventilating pump (a 20 × 24 in. KAP) was installed in a makeshift frame placed in the horizontal crawlway leading to the north entry.

11.3 Test Results

Contrary to our predictions, this lightly constructed shelter, tested closed, was undamaged by blast effects. The undamaged interior is pictured in Figs. 11.3, 11.8, and 11.9.

The triangular blast-protector logs around the doors, each 8 ft long and 7 to 8 in. in diameter, were moved away from ground zero, so

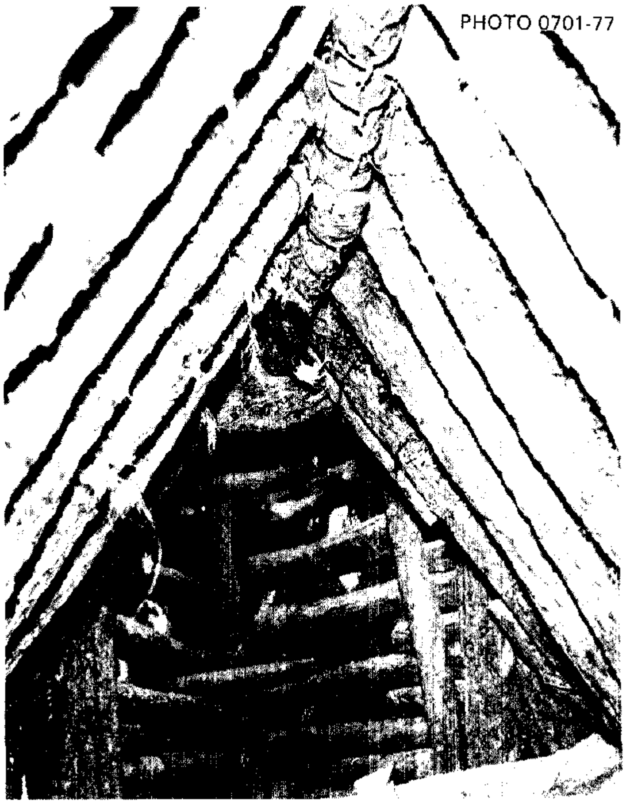

Fig. 11.8. Posttest view of opening at bottom of triangular vertical entry, undamaged by 20-psi blast effects.

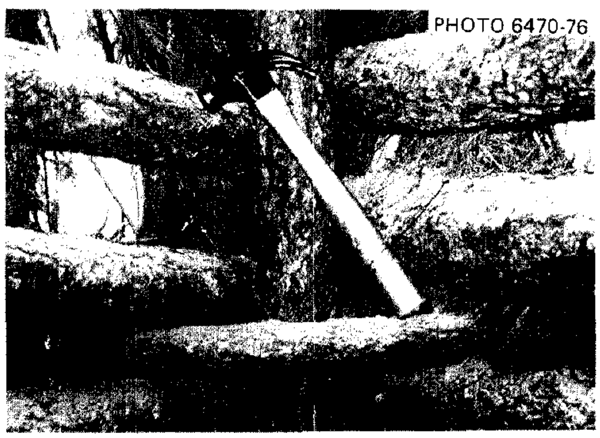

Fig. 11.9. Postshot condition of the lightly constructed triangular vertical entry. The hammer rests on a step pole. Earth arching prevented the yielding bed sheet outside from being torn.

that a log pressed against the blast-door hinges of each door (see Fig. 11.5). Both doors, however, could be opened. The blast winds scoured away about 8 to 10 in. of dry earth from around the six logs.

The blast valves on both doors obviously closed properly; a pressure rise of only 1 psi was recorded in the center of the shelter. The subsequently open valves permitted enough sand and dust to fall into the entries to have constituted a health hazard if heavy fallout had been on the ground outside. The ventilating pump and its flimsy frame were damaged slightly, but required only about 10 min to repair before post-shot testing.

The undamaged shelter frame was moved only slightly. The top of the roof was permanently depressed 1-5/8 in. and pushed 3/4 in. away from ground zero.

11.4 Conclusions and Recommendations

11.4.1. The Chinese "Man" Shelter, if built with the ORNL-designed triangular vertical entry and expedient blast doors, is a good example of the blast protection attainable by properly building a lightly constructed shelter that yields under blast loading so as to attain effective earth arching in an adequately thick earth covering.

11.4.2. We lack information concerning the magnitude and duration of the earth pressures produced by the blast on the wall poles — pressures that tend to collapse this A-frame structure. Therefore, we are unable even to hazard a prediction as to whether or not this closed shelter would survive the blast effects of a megaton weapon at the same 20-psi overpressure range, producing greater and much longer-lasting overpressures at depth, and ground waves of much greater amplitude.

11.4.3. During a rapidly escalating crisis, in many wooded areas the most difficult poles to supply in adequate numbers at shelter-building sites would be the long, straight, stout poles required to make rectangular entries to blast shelters. Therefore, triangular blast entries made of short, light poles and triangular expedient blast doors should be tested at higher overpressure and longer duration.

12. RUG-COVERED TRENCH SHELTERS AT 15 AND 5.8 psi

12.1 Purpose

Tarp-Covered Trench Shelters had been undamaged by heavy static and moving loads, including a 6-ton backhoe driven over the earth covering a shelter of this type roofed by a cotton tarp.[11] Since a cotton tarp is not as strong as a piece of typical wall-to-wall carpeting made largely of strong synthetic fibers, we anticipated this shelter would withstand the blast at the 15-psi overpressure range, by facilitating earth arching.

12.2 Construction

Figure 12.1 shows the principal design elements of a Rug-Covered Trench Shelter. The two models tested at DICE THROW had main-room

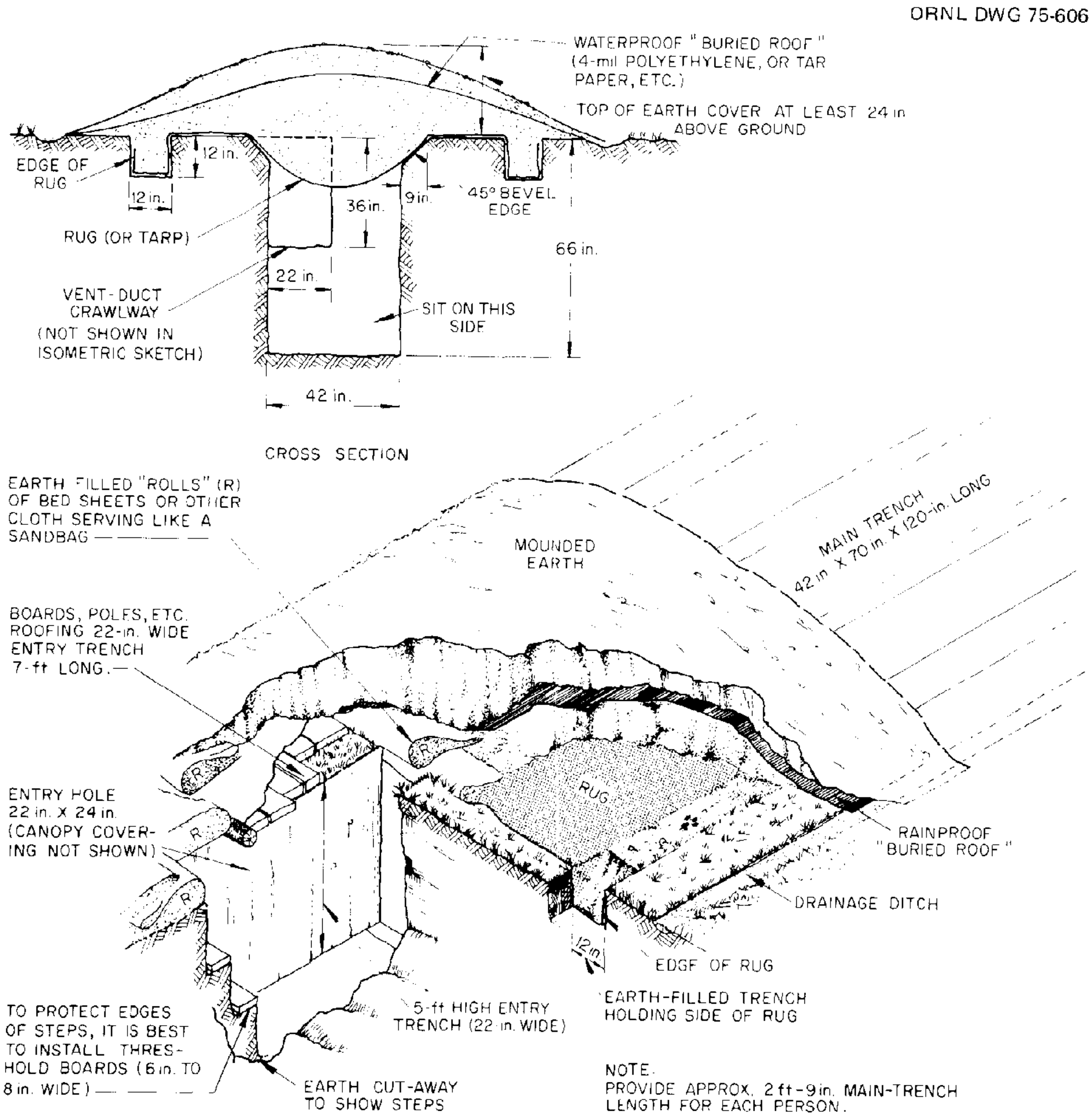

Fig. 12.1. Construction of Rug-Covered (or Tarp-Covered) Trench Shelter.

trenches 40 in. wide, 6 ft deep, and 11 ft long. The roofing rugs were each 12 ft wide by 11 ft long. These rugs had a double-laminated jute backing over nylon — typical low-cost wall-to-wall carpeting. No difficulties were experienced in covering the rugs with earth to a depth of 48 in. over the midline of the trench, nor in completing the 20-in.-wide entrances at each end (see Figs. 12.2 and 12.3).

PHOTO 6490-76

Fig. 12.2. Tamping earth over edge of a side trench of Rug-Covered Trench Shelter at 15 psi.

PHOTO 6491-76

Fig. 12.3. Dumping earth on side of rug before mounding earth 4 ft deep along centerline. An earth-filled bed-sheet "roll" and a pillowcase "sandbag" retained earth at each entry, pictured prior to completion.

12.3 Test Results

12.3.1. At 15 psi, the rug was torn lengthwise on one side from end to end, and the mass of overlying earth fell into the trench. This complete failure is shown clearly by Fig. 12.4.

12.3.2. At 5 psi, the rug was not torn, but the ground shock loosened it from the earth holding one of its edges in a side trench.

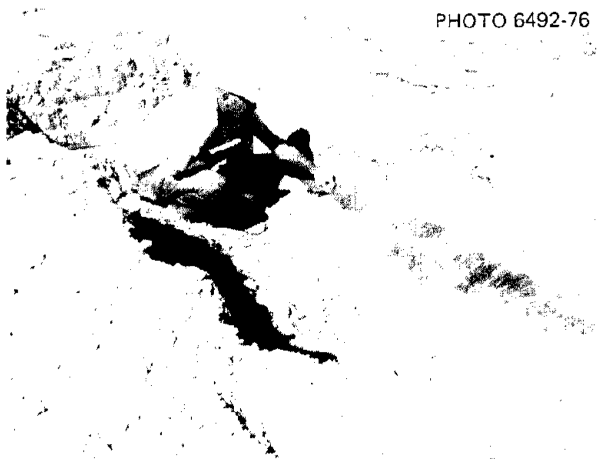

Fig. 12.4. Demolished Rug-Covered Trench Shelter at 15 psi. The edges of the rug were not pulled loose by blast effects; it was torn lengthwise.

As a result, the whole untorn rug and the mass of earth above it fell into the trench, to within about 18 in. of the trench floor. At this point, earth arching and the strength of the rug stopped the downward fall. Occupants sitting in the trench would have been crushed.

12.4 Conclusions and Recommendations

12.4.1. A Rug-Covered Trench Shelter definitely should not be built in areas likely to be subjected to blast effects.

12.4.2. A Rug-Covered (or Tarp-Covered) Trench Shelter should only be built for fallout protection, in an area where the earth is very stable, by persons lacking other materials with which to roof an expedient trench shelter.

13. SCALE MODELS OF SHELTERS

13.1 Purpose and Construction

In order to save money and to compare the resistance to blast effects of full-scale shelters with that of reduced-scale shelters, the scale models listed below were tested. All scale models were built of materials as similar as practical to those of their full-scale counterparts, and linear scaling of all dimensions was used in all cases.

13.2 Test Results

13.2.1 One-half-scale Rug-Covered Trench Shelters at 15 and 5 psi. Both shelters were undamaged by the blast effects, whereas their full-scale counterparts failed at the same overpressure ranges. The canvas used to roof the one-half-scale models was approximately one-half as strong as the wall-to-wall carpeting used to roof the full-scale shelters. For the one-half-scale models, a fabric only one-fourth as strong should have been used, since the weight of earth supported by a 1-ft-wide segment of the roofing fabric (measured along the edge of the trench) of the one-half-scale model is one-fourth as great as the weight of earth supported by a 1-ft-wide segment of the roofing fabric of the full-scale shelter ($1 \times 1/2 \times 1/2$ vs $1 \times 1 \times 1$). But even if we had selected roofing fabric only one-fourth as strong for the one-half-scale model, scaling would not have been satisfactory because the strength of the earth of the unsupported walls would have remained the same in both models, whereas the full-scale model to be equally strong would require earth having twice the resistance to shearing and tensile stresses.

Due to an oversight, samples of the rugs and canvas used to roof shelters were not preserved for materials laboratory testing. The relative amounts of stretch or yield of a fabric before tearing is probably more important than its ultimate tensile strength as a determinent of its value for roofing a blast-shelter trench.

13.2.2 Unshored earth walls of trench shelters. In all cases, at the same overpressure ranges the unsupported earth walls of small-scale trench shelters and of small-scale open trenches were less damaged by blast effects than were the corresponding walls of large-scale trench shelters and of large-scale open trenches. This was due to the fact that the volume of earth tending to be sheared off a trench wall by gravity and ground-shock forces increases as the cube of the increase in scale, whereas the area of the surface of the potential shearing-off of this volume increases as the square of the increase in scale. As a result of this difference, if we double all linear dimensions of a half-scale trench, then in the case of the full-scale earth wall a unit area of the surface of potential shearing is subjected to twice the unit stresses to which a corresponding unit area of the half-scale earth wall is subjected. Therefore, the full-scale trench wall fails first.

13.2.3 One-half-scale Chinese "Man" Shelter at 31 psi. This closed shelter (Fig. 13.1) was a one-half-scale counterpart of the Chinese "Man" Shelter tested at 20 psi, except that it had only one entry and had only one blast-protector log, which was 10 in. in diameter and secured by stakes.

The blast tore loose the blast-protector log. The blast winds, theoretically peaking at about 670 mph, hurled this log 180 ft, where it struck the side of the Ridge-Pole Shelter. About 10 in. of dry earth was scoured from around its entry. The earth shelves on which the lower ends of its side poles rested were cracked, but not broken off. About 2 in. of powdery caliche earth accumulated on the floor. The height of the shelter roof was reduced only 7/8 in.

Fig. 13.1. One-half-scale Chinese "Man" Shelter tested at 31 psi with its triangular blast door closed. Before being covered with earth mounded as high as the blast door, the whole shelter was covered with 4-mil polyethylene.

13.2.4 One-tenth-scale Chinese "Man" Shelter at 31 psi. This one-tenth scale model consisted only of a main room, closed at both ends with "poles," with its top at ground level. The frame was undamaged, but had been pushed into the sandy earth 2 in., reducing the ceiling height of the room from 4-1/4 in. to 2-1/4 in. (see Fig. 13.2). If a full-scale shelter built in soft earth had its poles proportionally

Fig. 13.2. One-tenth-scale room of Chinese "Man" Shelter at 31 psi, photographed posttest. The frame had remained adequately covered, was undamaged, but had been pushed about halfway into the ground.

pushed down into the earth by the 31-psi blast overpressure from a 1-megaton explosion, with its duration of overpressure ten times as long as from a 1-kiloton explosion, the intact survival of the shelter frame would be unimportant to occupants of this shelter.

13.2.5 One-half-scale Log-Covered Trench Shelter at 53 psi. This closed shelter consisted solely of a two-level room and a horizontal entry trench, counterparts of the adjacent full-scale Log-Covered Trench Shelter. Both of these shelters were built to compare the effectiveness of roofing a trench with poles laid on the surface of the ground as illustrated in Russian civil defense handbooks, as compared with the recommended Chinese procedure of placing the roofing poles on shelves well below ground level (see Fig. 13.3).

The blast damage suffered by both parts of this closed shelter indicated that occupants probably would have been injured, but was less serious than the damage suffered by its full-scale counterparts tested at 53 and 31 psi. In the Russian half, the upper parts of the earth walls were broken off, and the unbroken roof poles came to rest sloping,

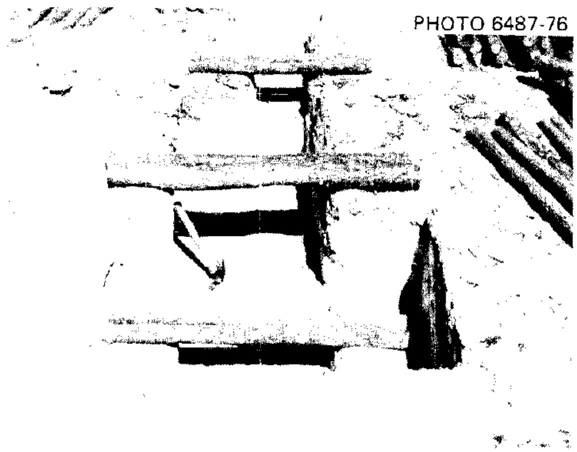

Fig. 13.3. Construction of one-half-scale Log-Covered Trench Shelter at 53 psi. The Chinese way of placing roofing poles below ground level is shown in front; the Russian way, to the rear.

with a reduction of 3-3/4 in. in midceiling height. In the Chinese half, the roof poles remained horizontal, although they were lowered 2-1/4 in. in the center.

13.2.6 One-tenth-scale Ridge-Pole Shelter at 15 psi. Unlike its adjacent full-scale counterpart, the entryways to this shelter were undamaged. However, as shown by Fig. 9.5, the earth covering the side of its frame facing ground zero and the tops of its entryways was completely removed.

13.2.7 One-tenth-scale Small-Pole Shelters at 53, 106, and approximately 180 psi. The shelter at 53 psi was undamaged, as was its full-scale counterpart at 53 psi. The shelter at 106 psi failed; one of its two vertical entries was wrecked, and lethal overpressures apparently entered through its smashed entry (see Figs. 13.4 and 13.5).

Fig. 13.4. One-tenth-scale Small-Pole Shelter, pretest at 106 psi. Earth was mounded over this shelter at slopes of about 10° to minimize blast-wind scouring. Only the plywood blast doors are visible.

Fig. 13.5. One-tenth-scale Small-Pole Shelter, posttest at 106 psi, shown after being carefully uncovered.

Neither of the 6-in.-deep earth covers of these one-tenth-scale shelters was seriously wind scoured. By contrast, their full-scale counterpart at 53 psi, shielded by an earth mound with slopes of 36°, lost over 8 to 12 in. of cover due to blast-wind scouring. However, the shielding earth over the one-tenth-scale models was mounded with slopes of only about 10°, and the wind velocities a few inches above the quite rough ground were not as high as those striking the 5-ft-high mound over the full-scale shelter.

At the approximately 180-psi overpressure range, a one-tenth-scale model of only the main room of a Small-Pole Shelter, tested closed and covered with 6 in. of unmounded sandy soil, survived. However, the wall poles were pushed down about one-third their heights, and the lower cross-bracing "ladder" broke, with poles left sticking upward into the living space, which would have injured or killed most occupants. At these overpressures it will be necessary to underlie the shelter with a floor identical to the roof, and probably to provide a crushable material, such as branches, under and around a full-scale shelter.

13.3 Conclusions

13.3.1. The successful testing of a reduced-scale shelter does not justify an assumption that its full-scale counterpart will survive as well in the same blast environment, especially under the dynamic loadings produced by large explosions.

13.3.2. When the critical stresses in full- and reduced-scale test structures (including stresses in earth banks subject to failure by shear) are induced by gravity and/or the acceleration or deceleration of masses, these stresses in the model are reduced by the scale factor.

13.3.3. Tests of small-scale shelters may be helpful in selecting the most promising of several designs for expensive full-scale testing.

14. BLAST-HURLED DEBRIS

14.1 Purpose

Blast tests have very rarely involved simulating the conditions of urban, suburban, or wooded areas as regards the damage likely to be caused by blast-hurled debris. Structures that could easily be damaged by heavy projectiles have frequently survived shock waves and blast winds because no materials to simulate houses and trees were placed between tham and ground zero (see ref. 3 for examples). Small expedient shelters, especially aboveground types and shelters with small, steeply sloped earth coverings, could be damaged or destroyed by blast-hurled heavy projectiles such as tree trunks or the parts of houses.

Therefore, to get at least a feeling for the magnitude of this neglected problem, we secured permission to expose to the blast some fireplace-sized logs, leftover lumber, a 14-ft-high complete tree "planted" securely in the hard caliche, and three 16-ft 2 × 4's also "planted" securely. Most of the logs were stacked in a woodpile at the approximately 70-psi range, with the logs pointing toward ground zero. Six logs averaging 8 in. in diameter were placed on top of the 5-ft-high mound of earth over shelters at 53 psi. The logs and boards were marked with paint of different colors, for posttest identification.

14.2 Test Results

The shock wave and blast winds hurled this debris farther than the standard blast wind velocities and theoretical calculations would lead one to believe. Most of the fireplace-sized logs came to rest 240 to 360 ft from their starting positions, and seven were airborne between 360 and 640 ft. The farthest airborne, a 5-in.-diam, 18-in.-long stick, came to rest 640 ft from the woodpile. Fourteen logs struck the 5-ft-high mound over the Log-Covered Trench Shelter at 53 psi and were embedded in the soft earth, as pictured in Fig. 14.1. Of the 73 pieces of blast-hurled debris that were found, 33 pieces were hurled between 240 and 360 ft and came to rest between approximately the 19- and 13-psi overpressure ranges.

The 14-ft-high tamarisk (salt cedar) tree, cut and "planted" two days before and still in full leaf, was broken off at the ground. Apparently, it was broken into very small pieces, and the pieces carried far away, since we were unable to find any part of this tree. The three vertical 2 × 4's were each broken into two or more pieces, some as short as 2 ft long.

Two of the small logs were hurled end-on into the earth bank over the shelters at 53 psi and punched into the bank about 15 in. deep, measured from the preblast surface of the mound (see Fig. 14.2). Most

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Fig. 14.1. Some of the fireplace-size logs hurled from a woodpile and embedded in the 5-ft-high mound at 53 psi. Apparently, the blast winds of the negative phase had uncovered the two small logs in the foreground and moved them toward ground zero.

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Fig. 14.2. Posttest condition of the side facing ground zero of the 5-ft-high mound of earth over Log-Covered Trench Shelter at 53 psi. The log sticking out of the mound had been hurled by the blast winds. The canvas had been covered with about 4 in. of earth, in a marginally successful attempt to reduce blast-wind scouring.

of the logs apparently bounced upward on hitting this bank (that sloped at about 36° toward ground zero) and were swept higher upward by the turbulent blast winds. None hit a blast-protector log around a blast door. Some came to rest when they struck shelter mounds farther from ground zero, as shown in Fig. 9.7.

14.3 Conclusions and Recommendations

14.3.1. Blast-hurled debris would constitute a serious hazard to most expedient shelters built in areas of the types where most Americans live or would evacuate into during a nuclear crisis, if these areas were subjected to severe blast effects.

14.3.2. For reasons explained in Sect. 18, it is extremely difficult to estimate from this evidence (based on a 1-kiloton air blast) the much greater hazards from blast-hurled debris likely to result at the same overpressure ranges from strategic nuclear weapons.

15. BLAST-WIND SCOURING

15.1 Purpose and Method of Measurements

Blast-wind scouring of dry earth mounded over expedient shelters at the usual slopes results in serious degradation of the fallout protection afforded.[9,10] In order to obtain data indicative of the depth of blast-wind scouring from various slopes of mounded earth, at DICE THROW we measured the depths of dry, sandy earth scoured from around fixed shelter entries and blast-protector logs, and also from around lines of 12-in. steel spikes driven into mounds at the 53-, 31-, 20-, and 15-psi overpressure ranges. Each line of four to seven spikes was on a radius from ground zero and extended from near the base of a mound to its top. The painted heads of these spikes were at the surface before the blast. Slope angles were measured with a Brunton pocket transit.

15.2 Test Results

The blast-wind scouring was more severe than anticipated. Most of the 12-in. spikes were blown away and lost, in spite of a search that involved raking. All spikes were lost from the 5-ft-high mound at 53 psi. (We should have used steel rods driven several feet into the ground.) Table 15.1 summarizes the measured and estimated depths of blast-wind scouring.

Table 15.1. One-kiloton blast-wind scouring from mounds of dry, sandy earth at different overpressure ranges and with different slopes

Overpressure (psi)	Slope (deg)	Depth of earth removed (in., measured perpendicular to the slope): Around spike on center of slope	Around spike on top of mound	From around entry or other rigid obstruction on top of mound
106	∿10	Negligible[a]	Negligible[a]	Negligible
53	36	Spikes lost, ∿12	Spikes lost, ∿12	∿12
	22	5	∿9	——[b]
	∿20	Spike lost	∿6	——
31	32	∿12	>12	17[c]
	17	2-1/2	Shelter collapsed	——
20	25	∿8	Shelter collapsed	——
	37	Spikes lost, ∿10	Spikes lost, ∿10	∿10
15	27	0	1-1/4	——
	35	2-1/2	6-3/4	——

[a]No spikes were driven into mound over the one-tenth-scale Small-Pole Shelter at 106 psi.

[b]—— indicates that no rigid obstruction was on top of a mound.

[c]Scouring was greater than at 53 psi because the mound was narrower and the one blast-protector log was blown away.

15.3 Conclusions and Recommendations

15.3.1. In order to prevent serious degradation of the fallout protection afforded by a shelter covered with dry, sandy earth if subjected to blast-wind scouring from a large nuclear explosion at overpressure ranges greater than about 30 psi, it appears prudent to mound earth over the shelter with slopes no greater than about 10°.

15.3.2. The effects of blast-wind scouring on different soils, mounded at different overpressure ranges and with different slopes and tested while wet, damp, and dry, should be determined by blast tests.

16. EXPEDIENT WATER STORAGE

16.1 Purpose

For a shelter to be occupied for weeks in an area of severe fallout hazards, adequate drinking water must be available close at hand. The survivors in areas likely to be subjected to both blast effects and heavy fallout should not depend on normal sources of drinking water or on water stored in containers likely to leak as a result of blast effects. Therefore, we conducted the first blast tests of simple, inexpensive expedient means for storing many gallons of water per shelter occupant.

16.2 Construction and Test Results

16.2.1 Water stored in plastic bags lining cylindrical pits in the earth.[12] As anticipated, lined cylindrical pits proved to be the most blast-resistant way to store water outside of blast shelters (see Fig. 16.1). Ordinary 30-gal polyethylene trash bags were used for waterproof liners. One bag was placed inside another, since a very small fraction of polyethylene bags not made for water storage have pinhole leaks. Each cylindrical pit was dug so as to have a diameter about 2 in. smaller than the diameter of its waterproof liner bag, when its liner bag was inflated.

The best way to keep the upper edges of the pit-lining bag from slipping into a pit is illustrated by Fig. 16.2: make a circular wire hoop the size of the mouth of the bag, and tape it into the mouth.

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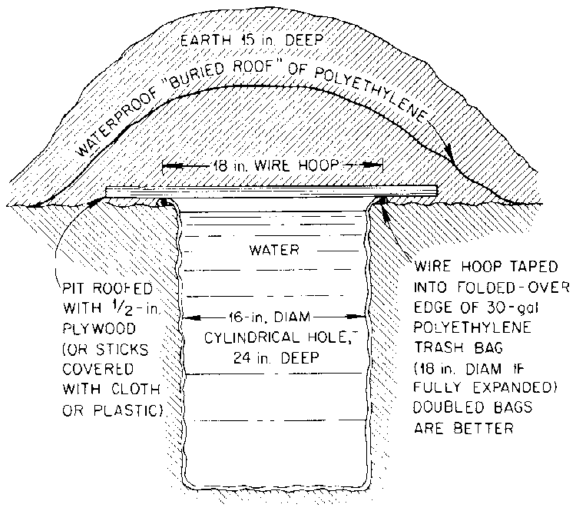

Fig. 16.1. Vertical section of cylindrical water storage pit lined with waterproof plastic bag, or two bags.

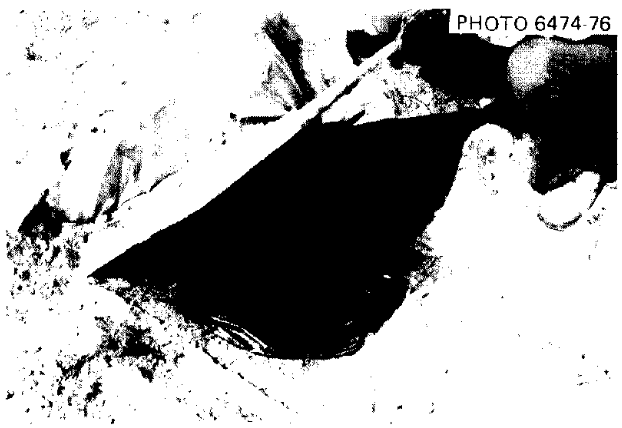

Fig. 16.2. Cylindrical water storage pit lined with two polyethylene trash bags. After exposure to blast effects at 20 psi, this pit was undamaged and still full of water.

This method was used in the water storage pits at the 20- and 6.7-psi overpressure ranges. At the 53-psi range, the upper edges of doubled bags were satisfactorily held in place merely by sticking six 4-in. nails through the turned-under edges of the bags and into the very firm earth.

Before the test, the lined pits, each approximately 2 ft deep, were filled almost full and then roofed and covered as illustrated by Fig. 16.1. Each lined pit contained about 20 gal of water. The earth cover was sufficiently thick to result in very effective earth arching under the blast loadings; both plywood pit roofs were cracked but not broken. None of the three storage pits developed leaks. Even at the 53-psi range, the blast effects resulted in no caving of the pit wall.

The storage pit at 53 psi, which after the blast was left partly open to the dry desert winds, showed only 4% loss of water after eight days. At the 20-psi range, after 24 days during which the pit was left completely open to the dry desert winds, it was about 70% full; and at 6.7 psi, the covered pit had lost only about 4% of its water after 24 days.

16.2.2 Water stored in one or two plastic bags used to line a smaller fabric bag or an ordinary pillowcase. This method can be used to transport and store quite large volumes of water.[12] Two burlap potato bags, each lined with two 20-gal polyethylene trash bags, were each filled with about 10 gal of water.

One of these expedient containers was tested inside the Small-Pole Shelter at the 53-psi overpressure range. Its mouth was tied shut with a 1/4-in. cord, one end of which was then tied to a nail driven into a wall pole of the shelter, about a foot above the top of the water bag. This cord kept the mouths of the burlap bag and its double lining bags above the level of the water inside. This water storage was unaffected by the quite severe ground shock inside the closed shelter.

Inside the open Russian Pole-Covered Trench Shelter at 6.7 psi, an identical water storage container was undamaged by the shock wave and blast winds that entered through the open stairway.

16.2.3 Water stored in plastic-lined trenches. Figure 16.3 is a postshot photo showing a lined water storage trench at 6.7 psi. This trench was dug 8 ft long, 27 in. wide, and 30 in. deep, and had been lined with a 10-ft-wide sheet of 4-mil polyethylene, with its edges secured in small, earth-filled ditches. About 200 gal had filled it to within about 6 in. of the top. The pit had then been covered with the pictured 3/4-in. plywood sheets. Earth had next been mounded about 30 in. deep over the plywood, incorporating a waterproof "buried roof" to keep

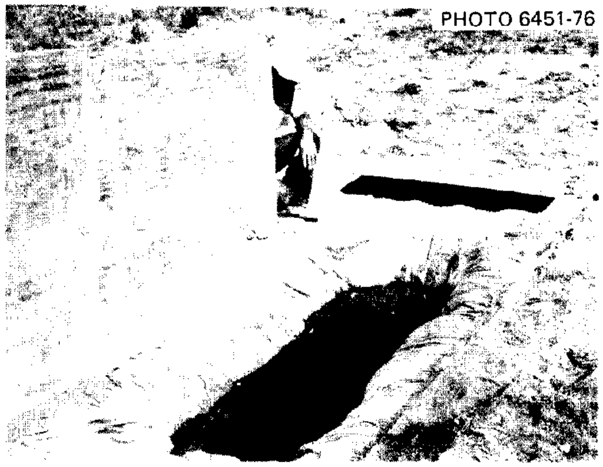

Fig. 16.3. Postshot view of plastic-lined water storage pit at the 6.7-psi overpressure range.

out fallout-contaminated rainwater. The resulting cross-sectional profile was similar to that shown in Fig. 16.1.

Ground shock resulted in some earth caving off the edges of the long sides of the trench, but no puncturing of the plastic lining resulted. Eight days after the blast, this sidewall caving had increased, but the trough still held a calculated 190 gal of water.

At the 20-psi range, a similar lined water storage pit was badly damaged by sidewall caving, although earth arching saved its roof. Before it could be examined after the blast, almost all of its approximately 200 gal of water had leaked out.

16.3 Conclusions

16.3.1. If blast is expected in a shelter area, plastic-lined cylindrical pits, filled almost full and protected from blast and contamination as illustrated in Fig. 16.1, would usually be the most practical method of expedient water storage.

16.3.2. Inside blast shelters, sufficient water for several days should be stored in fabric bags lined with larger plastic bags.

17. EXPEDIENT VENTILATION OF BLAST SHELTERS

17.1 Purpose

Expedient shelters that afford good protection against both blast and fallout have small entries, usually vertical. Such entries result in inadequate natural ventilation when a wind is not blowing. In hot weather, especially if it is humid, even with a breeze outside, a fully occupied shelter can become dangerously or lethally hot and humid. Furthermore, we recognized that air intake and air exhaust openings at ground level, if used for air supply in a blast-devastated area contaminated with heavy fallout, might have dangerous amounts of fallout blown into them (see Fig. 10.1).

The problem of pumping sufficient air through expedient blast valves of the types described earlier in this report needed investigation.

17.2 Observations, Construction, and Test Results

Intermittently during the three weeks following the main event, we observed the amount of sand and dust that was added to the amount that came through the poorly positioned blast valves in blast doors. Although in an area of very heavy fallout the amount that entered through these valves could prove serious, much more fell into the open entries of the shelters not partially protected by blast doors and the blast-protector logs around them.

The Small-Pole Shelter at 53 psi, which had solid plywood doors that had to be left partly open to secure adequate ventilation, presented a special problem. In an attempt to keep sand particles out, we built an improvised 1-ft-high "wall" of sticks covered with polyethylene around the vertical entry, inside the blast-protector logs, and over the whole entry we erected an expedient tent. These measures reduced by about 60% the amount of sand subsequently blown into the shelter. However, if the area had been covered with heavy fallout, it would have been impractical to work outside the estimated 20 or 30 min required to install two "walls" and two tents, even if all parts of the "walls" and tents had been carefully made to fit around and over the two shelter doors before the blast, and were stored inside the shelter for postattack use.

Ventilation tests, using expedient KAPs and making air velocity measurements with a Hastings anemometer, yielded the following results:

17.2.1. In the Log-Covered Trench Shelter at 53 psi, using a 20-in.-wide × 36-in.-high KAP (see Fig. 17.1), 412 cfm was pumped through the shelter when its blast doors were open; 177 cfm was pumped through the shelter with its two blast doors closed, with the air flowing through the blast valves. In each case a deduction was made for the small measured volume of air that moved through the shelter during times when the wind was blowing outside. Each door had blast valves with openings totaling about 80 $in.^2$ in cross-sectional area.

17.2.2. In the Chinese "Man" Shelter at 20 psi, using a 20-in.-wide × 24-in.-high KAP (see Fig. 17.2), with the two triangular blast doors open, 350 cfm was pumped through the shelter with the blast doors open; 240 cfm was pumped through the blast valves with the blast doors closed. Each door had valves with openings totaling about 115 $in.^2$ A gusty wind outside made these post test measurements less reliable, probably on the high side.

PHOTO 6182-76

Fig. 17.1. Expedient shelter ventilating pump (a 20 × 36 in. KAP) in an entry of the Log-Covered Trench Shelter at 53 psi. Tested pre-blast, it pumped 177 cfm through the valves of the two closed blast doors and 412 cfm with the doors open. This entry was demolished by blast effects.

PHOTO 6142-76

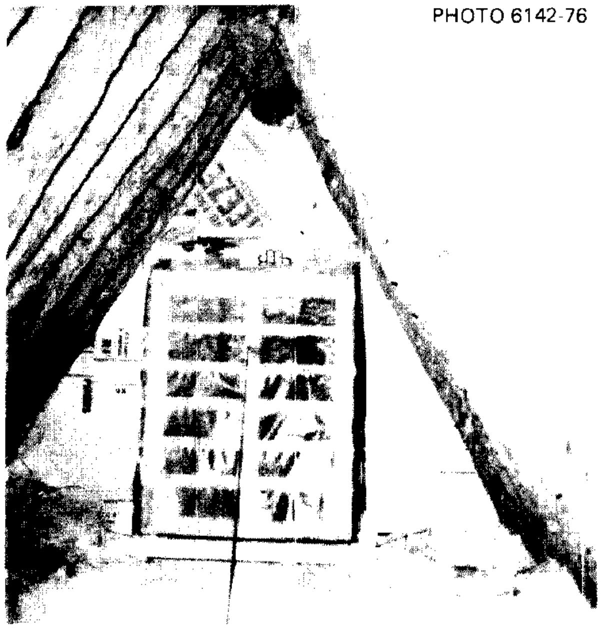

Fig. 17.2. Expedient KAP (20 x 24 in.) tested in the Chinese "Man" Shelter at 20 psi, after the blast.

17.2.3. In the Small-Pole Shelter at 53 psi, using a 29-in.-wide × 36-in.-high KAP when there was no wind outside, 861 cfm was pumped through the shelter while the two solid blast doors were each open about 1 ft, providing two openings each about 5 ft^2 in cross-sectional area. The fallout-protective "walls" and expedient tent were around and over the air intake entry during this test. (A similar test conducted before the blast, but with the doors completely open, resulted in a measured airflow of 876 cfm, see Fig. 4.6.)

17.3 Conclusions and Recommendations

17.3.1. Blast valves in blast doors are impractical. If valves of the type tested are mounted in separate vertical ventilation shafts, as was done in the ORNL tests in DNA's MIXED COMPANY main event,[1] the entry of fallout particles appears likely to be reduced below dangerous levels. Ways to build expedient ventilation shafts that do not require heavy lumber should be developed and tested.

17.3.2. Except in extremely hot and humid weather, an air supply of about 10 cfm per shelter occupant is enough to maintain tolerable conditions during continuous occupancy for several days. Therefore, even a KAP as small as 20 × 24 in. would usually prove adequate for a 15-man shelter protected by blast valves having total openings as large as those of the blast valves tested in DICE THROW (around 100 $in.^2$) but installed in separate air intake and air exhaust ventilation shafts.

17.3.3. Simple, expedient equipment to enable shelter occupants to raise ventilation air intake and air exhaust openings above ground level after the blast, and at the same time to quickly seal off the rest of the entries, should be developed and tested.

17.3.4. For use in prefabricated blast shelters or in blast shelters that may be built in normal times or during slowly worsening crises, ventilation pipes that are installed with their upper ends safely below the earth until after the blast, and that can be raised by a jack above ground level after the blast, should be developed and blast tested. (Since DICE THROW, we have designed and built a prototype of such an extendable ventilation pipe, and also a manually operated, homemade suction pump capable of pumping around 60 cfm through a 3- or 4-in. pipe.)

18. LIMITATIONS OF THESE DICE THROW TESTS

Caution should be used in extrapolating from the results of these DICE THROW tests to estimate the survivability of expedient shelters — especially those built in typical urban, suburban, or wooded areas — if subjected to the blast effects of a large nuclear weapon, for the following reasons:

18.1 Limitations Due to Size

This blast was small, with air-blast effects roughly equivalent to a 1-kiloton nuclear explosion. At locations receiving the same peak overpressures from a multimegaton surface burst, much more severe blast effects would result:

18.1.1. The duration of the overpressures and the dynamic overpressures would be much longer (20 times as long from an 8-megaton explosion),[3] and the energy transmitted to structures on and below the surface could be many times greater. At the same maximum overpressure ranges, the resulting destructive effects from an 8-megaton explosion on deeply buried parts of shelters and the unshored earth walls of shelters would be greater. Also the earth-flow phenomena observed (to a relatively minor extent in some of these DICE THROW tests) would certainly increase in some areas.

18.1.2. The damages due to ground shock would be more extensive due to the greater amplitude of the ground wave and (in the case of an 8-megaton burst) to the twenty-fold greater distances from ground zero to a given overpressure range. These greater distances usually would permit the ground shock to arrive at the ranges of interest up to hundreds of milliseconds in advance of the air shock wave; this difference between arrival times would cause the shelter roof supports to be accelerated upward before any downward forces from the airborne shock wave could cause downward movement of the earth covering a shelter. The vertical amplitude of such initial ground-shock (ground-wave) effects can be several inches, and the inertial mass response of the earth covering a shelter roof would thus cause the roof members to be bowed downward, to an extent not observable in high-explosive tests of similar shelters at similar overpressure ranges.

18.1.3. Earth scouring of aboveground mounds by the blast winds (that from an 8-megaton explosion would blow for about 20 times as long as from this "1-kiloton" DICE THROW shot) could be much greater, depending on the contour of the mound. Especially if the shielding earth were dry, such long-duration blast winds could blow away much of the shielding earth mounded above ground level over a shelter, possibly reducing its usefulness as a fallout shelter.

18.1.4. Blast-hurled heavy projectiles — including the trunks of large trees and parts of houses and other structures — can be accelerated by a 1-kiloton explosion to velocities only a small fraction of those to which the same objects, if at the same overpressure range, would be propelled by a multimegaton explosion. Persons estimating blast damage should remember that an object's kinetic energy varies as the square of its velocity. Furthermore, a hurled object having linear dimensions ten times as large as those of a small object having the same velocity, density, and relative proportions, and impacting in the same relative position on a fixed object, delivers ten times the amount of energy per square inch of impact area. Therefore, the impact damage to be expected from large objects accelerated by a multimegaton blast cannot be accurately estimated from the results of experiments like those at DICE THROW nor from the damage caused by blast-displaced heavy objects at Hiroshima and Nagasaki.

18.2 Blast Tests of Scale Models

Blast tests of scale models of shelters can give misleading results regarding the survivability of full-scale shelters subjected to the same blast effects. In the DICE THROW tests, all of the reduced-scale models of shelters withstood blast effects better than the corresponding full-scale shelters. For example, both of the half-scale Rug-Covered Trench Shelters tested at the 15- and 5.8-psi range were undamaged, whereas both full-scale models failed at the same overpressure ranges.

18.3 Earth Stability

The earth was extremely stable in the DICE THROW test area. At almost all of the ORNL DICE THROW shelter sites, at depths of only a few inches the sandy desert soil changes to very stable caliche. At the 53- and 31-psi ranges, the hardness of this soil, largely composed of sand grains cemented together with gypsum, approached that of a very soft limestone rock. Thus if shelters were built in typical inhabited areas — that have much less stable soils — and were subjected to blast effects similar in magnitude to those at DICE THROW, the collapse of the unshored walls of trench shelters, the pressures exerted on deeply buried parts of shelters, and the earth flow effects would all have been more pronounced and damaging.

18.4 Fire Dangers

18.4.1. The dangers from fires, carbon monoxide, and toxic smokes that would result from the thermal pulse and secondary blast effects of a nuclear explosion were not simulated at DICE THROW. Designers, advocates, and builders of shelters should become more aware especially of the dangers from carbon monoxide in blast-devasted areas. Soviet civil defense handbooks prudently state that in the "zone of total destruction" (the zone within the 7-psi contour) "the rubble only smolders."[6] Persons concerned with blast shelters should also be informed that even in areas of World War II mass fires, where less carbon monoxide was produced than if these same urban areas had been subjected to nuclear blast effects, often the majority of fatalities suffered by the occupants of shelters were caused by carbon monoxide. Thus some 70% of the 5000 persons who lost their lives in the well-prepared German city of Kassel were "asphyxiated, the greater part of them by poisonous carbon monoxide fumes."[18]

18.4.2. Whenever practical, shelters should be built well removed from buildings, flammable woods, and other readily ignitable materials, and the parts of shelters that are flammable and may be exposed to thermal pulse should be covered with a heat-reflective and/or fire-retardant coating. One of the means advocated in both Chinese and Russian civil defense handbooks for preventing thermal pulse or a nearby fire from igniting exposed flammable parts of expedient shelters is to paint these parts with a thick coating of slaked lime.[6,17] The World War II fire bombing of Kassel was less effective than in other German cities in producing fire storms because the roof timbers had been so treated.[18]

18.4.3. ORNL tests of this method included painting half of a dry, debarked log with a paste of slaked lime and then exposing the whole log to intense radiant heat from a very hot fire. The unpainted half burst into flames before the painted white part began to smoke much. If lime or white cement is not available, coating exposed wood, sandbags, etc., with ordinary neat cement, plaster, or even clayey mud should prove useful. Figure 18.1 illustrates blast-protector logs being quickly whitewashed. If water is available, keeping the exposed flammable parts of an earth-covered shelter wet, or even damp, will prevent their ignition by thermal pulse.

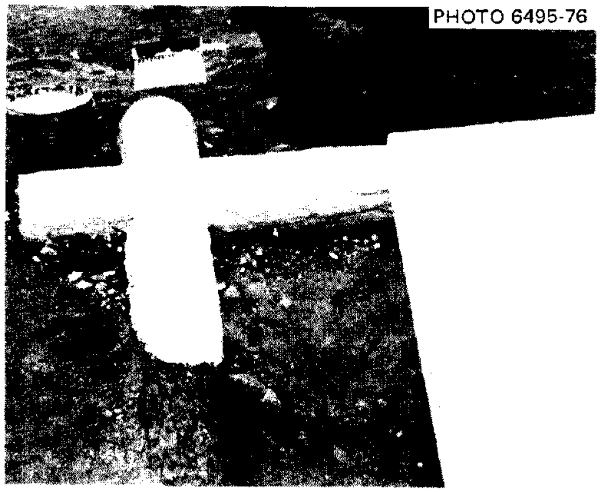

Fig. 18.1. Parts of a blast door and its blast-protector logs whitewashed with a thick slaked-lime paste. This is a proven effective means for making wood much more difficult to ignite.

19. PRINCIPAL CONCLUSIONS AND RECOMMENDATIONS

19.1. Expedient shelters of the types tested — especially if the ones with shored walls are equipped with blast doors — would afford better protection against the blast and fire effects of nuclear weapons and much better fallout protection than do all but a small fraction of existing buildings.

19.2. Ground-shock effects — not overpressure effects — would cause the failure of most expedient shelters with sufficient earth covering to assure effective earth arching. (In order to assure effective earth arching, the earth covering should be at least one-half as thick as the free span of the shelter roof. Also the roof and/or the whole structure must yield when loaded — thus causing the resultant earth arching around the structure to bear most of the load.)

19.3. Even in very stable ground, unshored trench shelters with ceilings about 6 ft high would be unsafe if subjected to the blast effects of large nuclear explosions at overpressure ranges of more than about 7 psi. Shelters of this same type with ceilings about 4-1/2 ft high would become unsafe at overpressures above 10 or 12 psi.

19.4. When roof cover is adequate to assure earth arching, flexible poles considerably smaller in diameter than those used to roof the ORNL shelters tested at DICE THROW should prove adequately strong.

19.5. Shelters likely to be subjected to blast effects should be built, whenever practical, with their roofs far enough below ground so that the tops of their entrances are no more than a foot above ground level. This positioning would greatly reduce blast damage and the removal of shielding earth by blast winds.

19.6. Expedient blast doors — especially doors made of poles and of triangular design — can be readily built strong enough to withstand as severe blast effects as the strongest expedient shelters tested to date. These doors should be blast tested while not protected by blast-protector logs, to determine whether such protection is essential.

19.7. Since the ground shock and earth flow effects from large nuclear weapons were not well simulated by the DICE THROW blast, expedient shelters and their life-support equipment should be tested under conditions more representative of large yields. The Air Force Weapons Laboratory's 125-kiloton dynamic air-blast simulation (DABS) test planned for March 1978 should provide a longer-duration blast environment more closely approaching that of the larger yields of interest.

19.8. Means for assuring adequate and safe ventilation-cooling of shelters after they have been subjected to severe blast effects is the most neglected essential component of shelter design. Future design and blast testing should include simple air intake and air exhaust openings of types shelter occupants could raise above ground level after the blast and that would enable them to pump sufficient air through their shelter while excluding dangerous amounts of fallout.

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